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GENERAL ZOÖLOGY

PRACTICAL, SYSTEMATIC AND COMPARATIVE

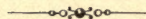
BEING A REVISION AND REARRANGEMENT OF
ORTON'S COMPARATIVE ZOÖLOGY

//

BY

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PREFACE

IN preparing this text-book of General Zoölogy an attempt has been made to meet the wants of teachers who desire a treatment of the subject somewhat different from that contained in earlier editions of Professor Orton's work, and to furnish a course of study suited to the needs of the general student who wishes to learn the principal facts and theories of zoölogy and thus to obtain a fairly comprehensive idea of the science. To this end it has seemed desirable so to arrange a course of study that the student may gain by personal observation concrete knowledge of the structure and activities of animals, and, by so doing, acquire some familiarity, slight perhaps, but nevertheless valuable, with the method of zoölogical investigation; that he may obtain also a knowledge of the relationships of animals as expressed in an accepted scheme of classification; that he may, further, broaden this knowledge by a comparison of animals in their structural and physiological relationships; and that, finally, he be placed in position to understand the significance of the more important theories of the science. With these aims in view the text of Professor Orton's "Comparative Zoölogy" has been revised and rearranged as described below.

The pedagogical importance of laboratory and field study has led to the introduction of a series of exercises upon the structure, physiology, and habits of representative animals. These exercises suggest the more important topics for study rather than give an inflexible outline to be followed in detail. The teacher is thus left free to adapt and modify the laboratory course to suit the peculiar needs of his classes and his equipment. The exercises lead to the study of Systematic Zoölogy, to which they serve as the natural introduction, the classification of animals being based upon their structural relationships. With the anatomy of the typical forms examined in the practical exercises in mind, the student ought to have no trouble in understanding the structural modifications mentioned in the descriptions of the principal classes and orders. Having thus enlarged his view of the animal kingdom, he is in position to appreciate the elementary facts of Comparative Zoölogy and to understand the main features of the current zoölogical theories. Believing this to be a logical sequence of study, the book has been arranged in accordance therewith. With the exception of slight changes, the laboratory exercises are the same as those recommended by the New York State Science Teachers' Association. The system of classification adopted is that given by Parker and Haswell in their "Text-book of Zoölogy," a work which will long be a standard of reference for teachers in secondary schools. Part I and Part II of Professor Orton's book have been transposed so as to place classification before the dis-

cussion of Comparative Zoölogy. The addition of a chapter on "The Origin of Animal Species" will, it is hoped, enable the student to understand the most important, at least, of zoölogical theories. A number of new figures have been incorporated. An asterisk at the head of a chapter indicates that the subject-matter of the chapter may be illustrated by practical work, for which directions will be found in the Appendix.

Acknowledgments are due to Messrs. D. Appleton and Company for permission to reproduce Figures 39(II) and 367 from Thomson's "Outlines of Zoölogy"; to the J. B. Lippincott Company for permission to reproduce Figures 207, 208, 212, and 256 from Piersol's "Normal Histology," and Figure 368 from Smith's "Economic Entomology"; to Messrs. W. B. Saunders and Company for permission to reproduce Figure 203 from G. C. Huber's edition of Böhm and Davidoff's "Text-book of Histology," and to Professor Alfred Schaper of the University of Breslau, for permission to reproduce Figure 211 from his edition of Stöhr's "Text-book of Histology."

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The first thing to be determined about a new specimen is not its name but its most prominent character. Until you know an animal, care not for its name. — AGASSIZ.

The great benefit which a scientific education bestows, whether as training or as knowledge, is dependent upon the extent to which the mind of the student is brought into immediate contact with facts — upon the degree to which he learns the habit of appealing directly to Nature. — HUXLEY.

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INTRODUCTION

1. Definition of Zoölogy, and its Place among the Sciences. — The province of *Natural History* is to describe, compare, and classify natural objects. These objects have been divided into the “organic” and the “inorganic,” or those which are, and those which are not, the products of life. *Biology* is the science of the former, and *Mineralogy* the science of the latter. Biology again separates into *Botany*, or the Natural History of Plants, and *Zoölogy*, or the Natural History of Animals; while Mineralogy divides into *Mineralogy proper*, the science of mineral species, and *Lithology*, the science of mineral aggregates or rocks. *Geology* is that comprehensive knowledge of the earth’s structure and development which rests on the whole doctrine of Natural History.

If we examine a piece of chalk, and determine its physical and chemical characters, its mode of occurrence and its uses, so as to distinguish it from all other forms of matter, we have its Mineralogy. But chalk occurs in vast natural beds; the examination of these masses — their origin, structure, position, and relation to other rocks — is the work of the Lithologist. Further, we observe that while chalk and marble are chemically alike, they widely differ in another respect. Grinding a piece of chalk so thin that we can see through it, and putting it under a microscope, we find imbedded in it innumerable bodies, about the hundredth of an inch in diameter, having a well-defined, symmetrical shape, and chambered like a nautilus. We cannot say these are

accidental aggregations, nor are they crystals; if the oyster shell is formed by an oyster, these also must be the products of life. Indeed, the dredge brings up similar microscopic skeletons from the bottom of the Atlantic. So we conclude that chalk is but the dried mud of an ancient sea, the cemetery of countless animals that lived and died long ago. The consideration of their fossil remains belongs to Paleontology, or that part of Biology which describes the relics of extinct forms of life. To study the stratigraphical position of the chalk bed, and by the aid of its Paleontology to determine its age and part in the world's history, is the business of Geology.

Of all the sciences, Zoölogy is the most extensive. Its field is a world of varied forms — hundreds of thousands in number. To determine their origin and development, their structure, habits, distribution, and mutual relations is the work of the Zoölogist. But so many and far-reaching are the aspects under which the animal creation may be contemplated, that the general science is beyond the grasp of any single person. Special departments have, therefore, arisen; and Zoölogy, in its comprehensive sense, is the combined result of the labors of many workers, each in his own line of research.

Structural Zoölogy treats of the organization of animals. There are two main branches: *Anatomy*, which considers the constitution and construction of the animal frame; and *Physiology*, which is the study of the apparatus in action. The former is separated into *Embryology*, or an account of the successive modifications through which an animal passes in its development from the egg to the adult state; and *Morphology*, which includes all inquiries concerning the form of mature animals, or the form and arrangement of their organs. The microscopical examination of any part, especially the tissues, belongs to *Histology*. *Comparative Zoölogy* is the com-

parison of the anatomy and physiology of all animals, existing and extinct, to discover the fundamental likeness underneath the superficial differences, and to trace the adaptation of organs to the habits and spheres of life. It is this comparative science which has led to such grand generalizations as the unity of structure amidst the diversity of form in the animal creation, and by revealing the degrees of affinity between species has enabled us to classify them in natural groups, and thus laid the foundation of Systematic Zoölogy. When the study of structure is limited to a particular class or species of animals, or to a particular organ or part, monographic sciences are created, as *Ornithotomy*, or anatomy of birds; *Osteology*, or the science of bones; and *Odontography*, or the natural history of teeth.

Systematic Zoölogy is the classification or grouping of animals according to their structural and developmental relations. The systematic knowledge of the several classes, as Insects, Reptiles, and Birds, has given rise to subordinate sciences, like *Entomology*, *Herpetology*, or *Ornithology*.¹ *

Distributive Zoölogy is the knowledge of the successive appearance of animals in the order of time (Paleontology in part), and of the geographical and physical distribution of animals, living or extinct, over the surface of the earth.

Theoretical Zoölogy includes those provisional modes of grouping facts and interpreting them, which still stand waiting at the gate of science. They *may* be true, but we can not say that they *are* true. The evidence is incomplete. Such are the theories which attempt to explain the origin of life and the origin of species.

Suppose we wish to understand all about the horse. Our first object is to study its structure. The whole

* See Notes at the end of the volume.

body is inclosed within a hide, a skin covered with hair; and if this hide be taken off, we find a great mass of flesh or muscle, the substance which, by its power of contraction, enables the animal to move. On removing this, we have a series of bones, bound together with ligaments, and forming the skeleton. Pursuing our researches, we find within this framework two main cavities: one, beginning in the skull and running through the spine, containing the brain and spinal marrow; the other, commencing with the mouth, contains the gullet, stomach, intestines, and the rest of the apparatus for digestion, and also the heart and lungs. Examinations of this character would give us the *Anatomy* of the horse, or, more precisely, *Hippotomy*. The study of the bones alone would be its *Osteology*; the knowledge of the nerves would belong to *Neurology*. If we examined, under the microscope, the minute structure of the hair, skin, flesh, blood, and bone, we should learn its *Histology*. The consideration of the manifold changes undergone in developing from the egg to the full-grown animal, would be the *Embryology* of the horse; and its *Morphology*, the special study of the form of the adult animal and of its internal organs.

Thus far we have been looking, as it were, at a steam engine, with the fires out, and nothing in the boiler; but the body of the living horse is a beautifully formed, active machine, and every part has its different work to do in the working of that machine, which is what we call its life. The science of such operations as the grinding of the food in the complex mill of the mouth; its digestion in the laboratory of the stomach; the pumping of the blood through a vast system of pipes over the whole body; its purification in the lungs; the process of growth, waste, and repair; and that wondrous telegraph, the brain, receiving impressions, sending

messages to the muscles, by which the animal is endowed with voluntary locomotion — this is *Physiology*. But horses are not the only living creatures in the world; and if we compare the structures of various animals, as the horse, zebra, dog, monkey, eagle, and codfish, we shall find more or fewer resemblances and differences, enough to enable us to classify them, and give to each a description which will distinguish it from all others. This is the work of *Systematic Zoölogy*. Moreover, the horses now living are not the only kinds that have ever lived; for the examination of the earth's crust — the great burial ground of past ages — reveals the bones of numerous horselike animals: the study of this preadamite race belongs to *Paleontology*. The chronological and geographical distribution of species is the department of *Distributive Zoölogy*. Speculations about the origin of the modern horse, whether by special creation, or by development from some allied form now extinct, are kept aloof from demonstrative science, under the head of *Theoretical Zoölogy*.

2. **History.** — The Greek philosopher Aristotle (384–322 B.C.) is called the “Father of Zoölogy.” Certainly, he is its only great representative in ancient times, though his frequent allusions to familiar works on anatomy show that something had been done before him. His “History of Animals,” in nine books, displays a wonderful knowledge of external and internal structure, habits, instincts, and uses. His descriptions are incomplete, but generally exact so far as they go. Alexander, it is said, gave him nine hundred talents to collect materials, and put at his disposal several thousand men, for hunting specimens and procuring information.

The Romans accomplished little in natural science, though their military expeditions furnished unrivaled opportunities. Nearly three centuries and a half after

Aristotle, Pliny (23-79 A.D.) wrote his "Natural History." He was a voluminous compiler, not an observer; he added hardly one new fact. He states that his work was extracted from over two thousand volumes, most of which are now lost.

During the Middle Ages, Natural History was studied in the books of the ancients; and at the close of the fifteenth century it was found where Pliny had left it, with the addition of many vague hypotheses and silly fancies. Albertus Magnus, of the thirteenth century, and Conrad Gesner and Aldrovandus, of the sixteenth, were voluminous writers, not naturalists. In the latter half of the sixteenth century men began to observe nature for themselves. The earliest noteworthy researches were made on Fishes, by Rondelet (1507-1556) and Belon (1517-1564) of France, and Salviani (1514-1572) of Italy. They were followed by valuable observations upon Insects, by Redi (1626-1698) of Italy, and Swammerdam (1637-1680) of Holland; and toward the end of the same century, the Dutch naturalist, Leeuwenhoeck (1632-1723), opened a new world of life by the use of the microscope.

But there was no real advance of Systematic Zoölogy till the advent of the illustrious John Ray (1628-1705) of England. His "Synopsis," published in 1693, contained the first attempt to classify animals according to structure. Ray was the forerunner of "the immortal Swede," Linnæus (1707-1778), "the great framer of precise and definite ideas of natural objects, and terse teacher of the briefest and clearest expressions of their differences." His chief merit was in defining generic groups, and inventing specific names.² Scarcely less important, however, was the impulse which he gave to the pursuit of Natural History. The spirit of inquiry, which his genius infused among the great, led to voy-

ages of research, which resulted in the formation of national museums. The first expedition was sent forth by George III. of England, in 1765. Réaumur (1683–1757) made the earliest zoölogical collection in France; and the West Indian collections of Sir Hans Sloane (1660–1752) were the nucleus of the British Museum. The accumulation of specimens suggested comparisons, which eventually resulted in the highest advance of the science.

The brilliant style of Buffon (1707–1788) made Zoölogy popular, not only in France, but throughout Europe. While the genius of Linnæus led to classification, that of Buffon lay in description. He was the first to call attention to the subject of Distribution. Lamarck (1745–1829) of Paris was the next great light. The publication of his “Animaux sans Vertèbres,” in 1801, was an epoch in the history of the lower animals. He was also the first prominent advocate of the transmutation of species.

But the brightest luminary in Zoölogy was George Cuvier (1769–1832), a German, born on French soil. Before his time “there was no great principle of classification. Facts were accumulated, and more or less systematized, but they were not yet arranged according to law; the principle was still wanting by which to generalize them and give meaning and vitality to the whole.” It was Cuvier who found the key. He was the first so to interpret structure as to be able from the inspection of one bone to reconstruct the entire animal, and assign its position. His anatomical investigations revealed the natural affinities of animals, and led to the grand generalization, that the most comprehensive groups in the kingdom were based, not on special characters, but on different plans of structure. Palissy had long ago (1580) asserted that petrified shells were of

animal origin ; but the publication of Cuvier's "Memoir on Fossil Elephants," in 1800, was the beginning of those profound researches on the remains of ancient life which created Paleontology. The discovery of the true relation between all animals, living and extinct, opened a boundless field of inquiry ; and from that day the advance of Zoölogy has been unparalleled. Special studies of particular parts or classes of animals have so rapidly developed, that the history of Zoölogy during the last fifty years is the history of many sciences.³

But to Charles Darwin more than to any other investigator is due the credit for the great mass of researches which has been accumulated during the last half century. The publication of the "Origin of Species," in 1859, marks the starting-point of modern zoölogical research. Darwin's statement of the facts of evolution and his theory of the causes which produce species of organisms, both plant and animal, attracted the attention of all biologists, and now practically all investigation in the sciences of zoölogy and botany is carried on in the light of the great principle of evolution.

PART I
STRUCTURAL AND SYSTEMATIC
ZOÖLOGY

Facts are stupid things until brought into connection with some general law. — AGASSIZ.

No man becomes a proficient in any science who does not transcend system, and gather up new truth for himself in the boundless field of research. — DR. A. P. PEABODY.

Never ask a question if you can help it; and never let a thing go unknown for the lack of asking a question if you can't help it. — BEECHER.

He is a thoroughly good naturalist who knows his own parish thoroughly. — CHARLES KINGSLEY.

STRUCTURAL AND SYSTEMATIC ZOOLOGY

CHAPTER I

PRACTICAL ZOOLOGY

It is very desirable that the student should get as much as possible of his knowledge of zoölogy from a study of the animals themselves rather than from descriptions. It is of course impracticable as well as undesirable to depend entirely upon this source of information. Nevertheless, the student should be taught *how* to study specimens, both living and dead. For this reason the following exercises in the practical examination of animal forms have been prepared. They consist mainly of mere suggestions of topics for study, the details being left to the teacher, for it is recognized that if a definite outline to be followed rigidly were offered, it would probably be too elaborate for those schools where only a few weeks can be devoted to the subject, and too meager for the schools in which a longer course is given.

The exercises provide for a study of the activities and habits of the living, as well as an examination of the structure of the dead specimen. Every important branch of the animal kingdom is represented by at least one common and easily obtained example. It is suggested that the example be studied before a text lesson is assigned on the group which it represents. In this way the student will have a certain amount of original

information which will enable him more clearly to comprehend the description of related forms mentioned in the text.

In every case careful drawings should be made of the specimen, and full notes on its habits and structure prepared.

The appliances needed are a scalpel and a pair of forceps, both of medium size; a magnifying glass; a compound microscope, if protozoa and other minute forms are to be studied; and a small board on which larger specimens may be laid for the study of the structure. If alcoholic specimens are to be studied they may be placed for examination in vegetable dishes containing equal parts of alcohol and water to prevent drying of the parts. There should be enough of the mixture to cover the specimen. Specimens which have been preserved in formalin may be examined in water. For more particular descriptions of specimens and methods of work reference may be made to the laboratory manuals and text-books mentioned in the Appendix.

INVERTEBRATES

Protozoa

Amœba

Material. — More or less uncertainty usually attends every attempt to provide at a given time a supply of amœbas for a laboratory class. Nevertheless, the study of this organism should not on any account be omitted, for from no other one is so much to be learned regarding the fundamental properties of living things. A thorough study of the amœba forms the basis of all sound biological training.

Specimens of amœba are often to be found in the

following places: in the slime on the under side of lily pads and along the stem; in the superficial layer of mud in ponds and slowly flowing streams; in damp moss from sphagnum swamps; in the deposit on the sides of water barrels in greenhouses; in aquaria which have been standing for some time *and which contain no crustaceans like Daphnia, Cypris, Cyclops*, etc. In case no specimens are obtained from ordinary sources, amoeboid cells may be used instead. These may be found by tearing to pieces the gills of a clam, or a mussel, or by killing a frog, cutting through the skin of the abdomen or leg, and removing a drop of the colorless fluid (lymph).

To study the specimen, collect with a pipette a drop of the water supposed to contain amoebas, or a drop of lymph, place it on a glass slide, put on the cover glass, and examine with a low power, $\frac{2}{3}$, $\frac{1}{2}$, or $\frac{1}{4}$ inch objective. Be sure to have some sediment or a hair under the cover glass in order that the weight of the latter may not crush the specimen.

Topics for Study. — The shape, an irregular outline, changing as the animal moves along (sketch the outline at intervals of one or two minutes, and compare the successive sketches); the motion, note its rate and direction; the change of shape is due very largely to the protrusion of portions of the body substance in the form of blunt processes called *pseudopodia* (singular, *pseudopodium*) (Fig. 1, page 57).

With a higher power ($\frac{1}{5}$ or $\frac{1}{6}$ inch objective), examine the animal's structure, noting that it is composed mainly of a clear, semifluid substance, — *protoplasm*, — in which are embedded numerous granular bodies of various sizes and colors, some recognizable as fragments of vegetable substance, together with, probably, one or more diatoms or other minute organisms. In some part of

the body there will usually be seen a large, clear, apparently empty circle, which from time to time suddenly contracts and disappears from view. This is the *contractile vacuole*, and is supposed to be an organ of excretion, since uric acid, one of the forms in which nitrogenous waste material leaves the body in higher animals, has been found in the vacuoles of certain animals closely related to the amœba. The vacuole, though apparently disk-shaped, is really spherical. Closer examination will show a small round mass, usually slightly darker than the rest of the body and often distinctly and evenly dotted with fine points, and surrounded by a plainly defined line. This is the *nucleus* surrounded by its membrane. Its shape is constant, except when the amœba is in the process of division. Still more careful study will show that the body substance can be rather sharply divided into two regions, an outer, clear, quite homogeneous portion, the *ectoplasm*, and an inner, granular region, the *endoplasm*.

If the animal be watched for a short time, it will probably be seen to ingest food particles, or, possibly, capture another animalcule. In either case, the mode of procedure should be watched and the fate of the captured particle followed. Some of the ingested material will be disgorged, while certain pieces will be seen slowly to disintegrate and to disappear as they dissolve in the droplet of water in which the animal swallowed them. From the behavior of these particles and from the changes seen to take place in substances which have been given the amœba for experimental purposes, it is believed that the animal produces in its body substances analogous to the digestive juices of higher forms. The disintegration of the food particles, then, indicates that they are being digested. When they have reached the stage of solution, they can, of course, no longer be seen.

The process of respiration cannot be followed in this organism, there being no definite organs analogous to the gills and lungs of higher forms devoted to this function; but the interchange of oxygen and carbon dioxide, which is the essential part of the process, is believed to take place through the superficial part of the body.

The nervous properties of the animal are well shown when it comes in contact with a foreign body, evidence for the possession of the sense of touch being easily obtained while the movements are being watched.

The contractions of the body substance show that it is muscular.

In exceptional circumstances, an amœba in the process of division, or fission, may be found, the body separating into two parts connected at first by a thread of protoplasm which eventually breaks, two distinct organisms thus being formed. This process may be more easily studied, however, in *Paramecium*, the "slipper animalcule." Preceding the division of the single cell composing the body, there is a division of its nucleus. Some of the "shelled" forms, like *Arcella* and *Diffugia*, may be used for comparison.

Euglena

Material. — Some of the green scum which forms on the inside of aquaria is likely to yield abundant specimens. If not, they may usually be raised by allowing some pieces of green-coated bark, or a portion of a flowerpot covered with the green film which forms on the sides of damp pots, to stand covered with water in a dish in a sunny place for several days. Scrape off some of the green film in the bottom of the dish, and examine according to the directions given for amœba. The animal may be recognized by its green color,

amœbalike changes in the shape of the body, and by the presence of a whiplashlike organ (flagellum) by means of which it propels itself through the water.

Topics for Study.—The elongated, highly flexible body, its motions and color; the position and movements of the flagellum; the red stigma, or “eye spot,” and the contractile vacuole, both near the mouth (Fig. 4).

Paramecium

Material.—The slipper animalcule is more readily obtained than almost any other of the protozoa. There are various ways of raising it in abundance for laboratory purposes. Hay or marsh grass cut into pieces a few inches long may be placed in a convenient dish, covered with water, and set in a warm room for one or two weeks, at the end of which time there will probably have formed a pellicle on the surface. This will consist largely of rod-shaped or threadlike bacteria, and feeding upon them will be seen many kinds of infusoria, among the latter being *Stylonychia*, which may be recognized by its large bristlelike cilia and its springing motions, and *Paramecium*, the “slipper animal,” covered everywhere with fine cilia and having a more smooth, gliding movement. Another satisfactory method of procuring specimens is to place a handful of water plants, like *Anacharis* (waterweed), *Utricularia* (bladderwort), or *Potamogeton* (pondweed) in just enough water to cover the plants, and let the mass stand in a warm, dark place until decay begins, at which time the water will probably be found to be swarming with animalcules.

In preparing the specimens for microscopic examination, follow the directions given for amœba. It is always well to put under the cover glass a few fragments of the scum consisting of bacteria, for the animalcules will gather around these masses and remain,

feeding quietly. Otherwise their motions are likely to be so rapid that study of the specimen may be quite impossible. Or, a few fibers of absorbent cotton may be placed in the drop of water containing the animals, thus forming meshes to entangle them.

Aquarium Study. — In the culture note the swarms of animalcules, their position with reference to the surface of the water, the sides of the dish, the direction of the brightest light; their size, color, and movements.

Microscope Study. — With the low power study the movements, their direction and rate; the flexibility of the body, as seen when the animal passes through narrow openings or around corners; the definite shape of the body (compare with *amœba*); the nervous properties, especially the sense of touch exhibited when the animal comes into contact with a foreign body; the tendency to collect around food masses and air bubbles, or near the margin of the cover glass, the latter tendency best seen if the water is very foul; animals in the process of fission (resembling a single specimen more or less constricted in the middle of the body, Fig. 10), or in conjugation (two individuals attached together by their ventral sides).

With the high power the structure of individual animals and the functions of various parts of their bodies may be studied. Note the arrangement, shape, size, and movements of the cilia (their motions may be stopped by the application of a drop of iodine solution); the presence of the cuticle (cell wall); the mouth opening leading to the gullet, the latter lined by short cilia whose motions cause a current of water bearing food particles to pass down into the body, where droplets (food vacuoles) form and, after reaching a fairly uniform size, are separated from the end of the gullet and carried around through the body by the flow of the body sub-

stance (protoplasm); the position and movements of the contractile vacuoles, one near each end of the body, by means of which the waste water is removed from the body; the movements of the cilia near the mouth opening which produce currents in the water, thus bringing food particles within reach; the trichocysts, thought to be organs of defense, lying parallel to one another just under the cuticle (their discharge may be produced by running a drop of acetic acid under the cover glass); the large nucleus may be seen lying near the center of the body after the application of a drop of acetic methyl green or of methylene blue (Fig. 9).

Evidence of the possession of nervous properties will be seen in the animal's extreme sensitiveness to contact with foreign bodies, in its selection of food, which consists almost entirely of bacteria, in its tendency to collect on the lighter side of the aquarium jar when the latter stands remote from the window.

Attention should be called to the possible means of dispersal of the animal, to its value as a scavenger, and particularly to the "physiological division of labor" among the various portions of its body, which, though a single cell, has its parts very plainly adapted to perform many different functions.

Vorticella

Material.—Specimens are usually to be found attached to the sides of the aquarium in which *Paramecium* has been raised, or to the fragments of hay, water plants, etc., therein. Prepare the specimens according to the directions for *Amæba*.

Topics for Study.—With the low power study the shape of the animal, consisting of the body portion and the flexible stalk; the movements of each part, especially the coiling of the stalk; the position and movements of

the cilia, note that the latter are confined to the margin of the bell-shaped body ; the miniature vortex into which food particles are drawn by the action of the cilia.

With the high power, study the position and shape of the large crooked nucleus, the motions of the single contractile vacuole, the structure of the stalk, and the ingestion of food particles (Fig. 11, *b*). Some specimens will probably be found in the state of fission. The early stages may be identified by the broadening of the body transversely, the absence of cilia, and by a vertical groove indicating the direction of division. Later the two parts become more or less completely separated, one having a circle of cilia around its lower portion. A few minutes after the cilia are formed the animalcule breaks away from its companion, leaving the latter in possession of the stalk, and swims away by means of its temporary locomotor cilia to select a site for attaching itself and developing its own stalk (Fig. 11, *a*).

Conjugation may sometimes be observed, and may be recognized by the fact that a large stalked individual has attached to the lower portion of its body a much smaller nonstalked individual, which gradually merges into the body of the larger animal and disappears. The nuclei of the two individuals fuse together and fertilization is thus accomplished, but the changes which take place within the two cells during the process of conjugation can be demonstrated only upon specimens especially prepared for this purpose, the method of preparation being too intricate for beginners.

Metazoa

Porifera

Material. — Simple marine sponges may be obtained of dealers in laboratory supplies. Fresh-water sponges, *Spongilla* (green) and *Myenia* (brown) are to be looked

for in *clear* water attached to submerged branches, logs, and rocks, and especially on the timbers of dams and mill races. In purchasing toilet sponges for specimens, care should be taken to select some which show single, others numerous, openings and canals, while still others should have particles of sand and of shells embedded in the lower part.

Using *Grantia* as a type of the simple sponge, study its shape, color, and mode of attachment; the large opening (osculum) at the upper end surrounded with a row of spicules. Note the small openings, *inhalant pores*, on the surface. Cut the sponge open longitudinally and note the pores opening into the central cavity. These pores will be seen to be the ends of canals which run horizontally outward. They do not, however, open to the outer surface. These are the *radial canals*. Lying between two adjacent radial canals will be found an *incurrent canal*, the outer opening of which is on the outer surface of the sponge. This canal has no opening directly into the central cavity. Water carrying food particles is drawn into the incurrent canals and passes into the radial canals through pores in the walls of tissue between the two canals. It then passes out of the pores at the inner ends of the radial canals, into the larger central cavity, and out through the osculum. The flow of water is produced by the action of ciliated cells which line the radial canals (Figs. 13, 14).

Microscopic sections will show the arrangement of the canals and of the spicules of lime in the tissue of the sponge, as well as the arrangement of the cellular parts of the body. Large amœboid cells (ova) are frequently found in the walls between the canals. The spicules may be obtained free from adhering tissue by boiling a fragment of *Grantia* in caustic potash in a test tube. As the spicules do not dissolve, the fluid may be drained

off and a drop of the sediment in the tube placed under the microscope for examination. If a fragment of *Grantia* be placed in weak acetic acid, an abundant effervescence will take place, giving evidence that the spicules are composed of carbonate of lime, the rest of the sponge body remaining undissolved.

In studying the toilet sponge, note its color, shape, weight, and elasticity; study the position and arrangement of the large and small canals; note the embedded sand particles, shells, etc.; the texture of various specimens; put a fragment under the low power of the microscope and note how the fibers are arranged; soak a sponge in water and measure the amount held in the meshes by squeezing it out into a graduate.

Fresh-water sponges are not easily kept alive in the laboratory nor is their structure very plain. Their mode of growth, branching, color, and friable texture may be studied. With a magnifying glass numerous pores will be seen on *Spongilla*, while the oscula of *Myenia* are plainly visible. Microscopic sections will show the double-pointed, flinty spicules traversing the tissues in all directions. Small spherical, seedlike gemmules may be obtained in the older part of the sponge in the fall, and will "germinate" in a few days if kept undisturbed in a dish of water. Only very little growth is likely to take place.

Cœlenterata

Hydra

Material.—Either the green or the brown species may be used; the latter, being much the larger, is preferable. It will be found attached to the stems of water plants which may be kept in aquarium jars. The animals will often migrate to the sides of the jar, where they can be studied with or without a lens.

The green species is common on species of *Vaucheria* or greenfelt, which grow in rapidly flowing creeks. Mats of the plant may be put into white earthenware dishes. After a few minutes the hydras will expand and be easily seen against the background formed by the dish.

Aquarium Study. — With the naked eye or with a lens study the hydra *in situ*, noting its color, shape, size, the body and the tentacles, the number and extensibility of the latter; touch the body or the tentacles with a bristle and note the sensitiveness of the animal. Look for individuals bearing buds; the number and position of the latter; the radial symmetry of the body. Note how well the shape and color of the animal adapt it to its surroundings (Fig. 17).

Microscope Study. — Transfer a fragment of the plant bearing a hydra to a watch glass (or, if the animal is fastened to the side of the jar, detach it with a pipette), and examine under a lens or under a low power. Note again the movements of the body and tentacles. Put a minute fragment of fresh meat within reach of the tentacles and endeavor to see the hydra catch and swallow it. Study the movements of the mouth.

Mount a specimen under a cover glass and study the structure of the body, its walls consisting of two layers of cells; the central cavity with one exterior opening; the color of the inner cell layer and its cause; the structure of the tentacles, the groups of nettle cells; cause the discharge of the latter by running a drop of weak acetic acid under the cover glass. On individuals bearing buds study the structure and actions of the latter; their mode of attachment to the parent; the small "colony" formed by this mode of reproduction (Fig. 18).

Note the effect of light on hydras by putting several in a jar of water and covering it with an opaque paper through which on one side a hole one inch in diameter has been made, the jar then being placed near a window and the hole being directed toward the light.

For comparison use the sea anemone, *Metridium* (Fig. 236).

Campanularian Hydroid

Material. — Specimens of *Eucope* or *Obelia* are found attached to seaweed or submerged timbers, below low tide mark, in the sea. The colonies are usually grayish in color, much branched, and have a noticeably plant-like aspect. If living specimens are available for study, they may be placed in small dishes of fresh sea water and examined with a magnifying glass. The various motions of the polyps may be studied, their protrusion from and withdrawal into the protective cup which surrounds each one, the rapid extension and twisting of the tentacles, the protrusion of the funnel-like mouth to engulf particles of food (minute scraps of fresh meat are suitable), the sensitiveness of the various members of the colony to jarring, touching with a bristle point, agitation of the water, and so on (Fig. 20).

It will be noticed that the colony consists of two forms of zoöid, one bearing tentacles, the nutritive zoöids; the other being without tentacles, elongated in shape, and containing a number of rounded bodies. This form is the reproductive zoöid, and the contained bodies are the medusa buds or medusoids, which, when mature, are liberated and produce the eggs from which new, branched colonies arise. The phenomenon of "alternation of generations" is here very marked.

The microscopic structure is best seen in mounted specimens, which may be obtained from dealers.

Platyhelminthes and Nemathelminthes

Tapeworm, or Trichina

Material. — Alcoholic specimens of the former and microscopic preparations of the latter may be studied and attention called to their complicated developmental history, and their pathologic significance (Figs. 37, 38, 39).

Echinodermata

Starfish

Aquarium Study. — If live specimens can be obtained, study their mode of locomotion; the flexibility of the rays and the body; the movement of the spines along the grooves, around the mouth opening, and at the tip of the ray where the eye is located; note the sensitiveness of the various parts, particularly of the tube feet and of the branchiæ; note also that the numerous tube feet move as though regulated or coördinated by some governing power, their movements being thus directed toward the attainment of some definite end instead of being at random. Examine a number of specimens and look for variations in the size of the rays. These will show the power of regenerating lost parts, which the starfish possesses to a high degree.

Structure. — Study the position and arrangement of all external parts, the spines, tube feet, eyes, branchiæ, madreporic body, peristome, the radial nerve in the roof of each groove. Remove the upper half of the outer "shell" and note the internal organs: the digestive system consisting of the stomach and digestive glands; the internal parts of the water-vascular system, the water sacs and the "stone canal"; the reproductive glands; note the radial plan of structure (Figs. 46, 323, 330).

Exhibit a series of eggs, showing different stages of segmentation, also the larval forms of the starfish.

Sea Urchin

Aquarium Study. — Note its mode of locomotion, its sensitiveness, its movements in righting itself after having been turned bottom side up.

Structure. — Trace all the resemblances you can between its external structure and that of the starfish. Note that in spite of their difference in shape their likeness in structure is very marked. Study the digestive system, the teeth, and the long intestine. Note the radial symmetry (Figs. 48, 226, 237, 293, 294).

Exhibit the larval stages.

The cake urchin (*Echinarachnius*) and the holothurian (*Holothuria*, *Thyone*, or *Synapta*) may be used for comparison (Fig. 49). No other group of animals shows so well as the echinoderms that the same plan of structure may be associated with the greatest diversity of external form.

Annulata

Earthworm

Field or Vivarium Study. — Study living specimens out of doors, note their castings along paths, the amount of earth brought up; the diameter of the burrows; trace the latter down into the soil. Place a live worm on the surface of the soil and note its mode of locomotion; its method of burrowing; the protection from enemies afforded by its color; draw one out of its burrow and note the resistance; touch a worm with a bristle and note its sensitiveness; note the effect of plugging the mouth of the burrow with bits of straw, leaves, etc.

Watch the pulsation of the dorsal blood vessel.

Structure. — Note the shape of the body, the rings composing it, the girdle, the mouth, the anus, the openings of the reproductive glands, the bristles.

Cut an alcoholic or formalin specimen open along the

middle of the back and examine the muscular wall of the body; the tough, transparent cuticle; the alimentary tube within with the blood vessel and digestive gland on its upper side; the partitions connecting the digestive tube with the body wall; the long series of cavities nearly separated from one another by these partitions, the whole forming the body cavity; the continuous digestive canal opening at each end to the exterior; the pair of excretory organs in each separate cavity. Study the digestive tube, consisting of pharynx, esophagus, crop, gizzard, and intestine; note the structure of the wall of the tube in each of these regions; the supra-esophageal ganglion or "brain" lying above the pharynx; the nerve cord below the alimentary canal; the reproductive glands along the anterior part of the canal; note the bilateral arrangement of all organs; also that the principal parts of the circulatory system lie above, and of the nervous system below, the digestive system (Fig. 52).

Draw attention to the economic and geologic importance of the earthworm in overturning the soil as it feeds and constructs its burrows. If cocoons (egg capsules) can be found (often attached to straws around manure heaps) examine the various stages of development of the earthworm.

The leech and *Nereis* (Fig. 215) or *Arenicola* (Fig. 274) may be used for comparison.

Arthropoda

I. CRUSTACEA

Crayfish or Lobster

Material.—Live specimens of the former may be kept indefinitely in aquarium jars containing algæ and supplied at intervals with a few crumbs or fragments of beef or fish.

Aquarium Study. — Watch their movements when walking and swimming; the various motions of which the legs are capable; the movements of the antennæ, eyes, and swimmerets; the position of the abdomen; the manner in which food (a scrap of fresh beef) is held and pieces put into the mouth; the movements of the jaws; of the breathing organs; the position of the eggs, if a female “in berry” can be obtained; the means of offense and defense.

Structure. — With a dead specimen, preferably alcoholic, note the hard covering of the body; the two regions (cephalothorax and abdomen); the rings or segments of which the latter is composed; the membranous parts between adjacent rings; the indications of segmentation seen on the under side of the cephalothorax; the number and structure of jointed appendages on the abdomen; the use of each kind; the number, structure, and use of the locomotor appendages on the cephalothorax; the specialization of each pair for particular functions; the relation between legs and gills; the arrangement, structure, and use of the various mouth parts; the structure of the eyes and “feelers”; the ear; the protection of the gills; endeavor to make out the fundamental plan of structure which underlies the great diversity of form shown by the various appendages (Fig. 54).

Cut through the shell along each side and remove the upper part, thus exposing the internal organs. Note the large muscles in the abdomen; the pericardium and heart with the large artery running backward along the middle line of the large abdominal muscle; the stomach with the bonelike parts in its walls; the intestine; the digestive glands; the esophagus; the reproductive glands; the “green glands” (in the crayfish); the nerve cord lying below the digestive system; the

“brain”; note the tendency of ganglia to fuse into larger nerve centers (Figs. 55, 267).

Exhibit a series of larval crayfishes or lobsters, showing the changes undergone at each molting.

Try to get specimens of the lobster, showing the regeneration of lost parts, specially the pincers.

Call attention to resemblances in structure between earthworm and crayfish; note in the latter the tendency to collect into definite regions the organs devoted to definite uses; also that every segment bears a pair of jointed appendages.

Use the crab (*Callinectes*) for comparison.

2. INSECTA

Grasshopper

Living specimens may be kept in boxes or jars covered with gauze or netting and kept supplied with plenty of fresh grass or wheat.

Field and Vivarium Study. — Note how the insect walks, leaps, and flies; the length of a single leap; how the food is held and eaten; the use of the various sense organs, as eyes and feelers; the mode of breathing; the protective coloration of the body.

Structure. — Note the three regions of the body (head, thorax, and abdomen), comparing with crayfish and spider; study the structure of each region; the appendages borne by each region; their use; the structure of each kind of appendage and its adaptation to its special function; the spiracles; the ovipositor on the female; the ear (Figs. 64, 219, 276, 295, 344, 352).

Cut open a specimen lengthwise and note the parts of the digestive system; the muscles; the reproductive organs; the structure and arrangement of the nervous system. Examine tracheal tubes with the microscope (Figs. 239, 277, 278).

Compare the plan of structure of the grasshopper with that of the earthworm, crayfish, and spider.

Try to get young grasshoppers and note the changes which are shown at the successive molts.

Butterfly

Field and Vivarium Study. — Note its wavering flight, the way it walks, the position of the wings when at rest, the use of the proboscis when gathering nectar, the species of plants visited, the position of the proboscis when not in use.

Structure. — Note the similarity of structure to the grasshopper; the differences between the wings of the insects; the greater uniformity in the structure of the legs of the butterfly; the position of the eyes; the shape of the antennæ; the structure of the proboscis; the microscopic appearance of the scales on the surface of the wings (Figs. 70, 71, 221, 238, 241).

Examine the larva, noting its shape and color; its mode of locomotion; locomotor organs; food and method of feeding (Fig. 73). Put mature larvæ (of Mourning Cloak butterfly, for example) in a glass-covered box and watch them as they change to the pupa stage.

Study the chrysalis and eggs, if obtainable (Fig. 368).

The bee, fly, and beetle may be used for comparison.

3. ARACHNIDA

Spider

Field and Vivarium Study. — Study the mode of locomotion; the position, arrangement, and captured contents of a web; the position of the spider in the web. Put a spider into a large pasteboard or wooden box, cover with a sheet of glass, and note how the silk is spun and the web is constructed. Look for cocoons and study their structures and contents.

Structure. — Note the same regions as in the crayfish (cephalothorax and abdomen); study the points of resemblance and of difference; indications of segmentation shown by each; compare the number, position, and structure of the legs; study the spinnerets, their position, number, and form; the mouth parts; the eyes; the structure and appendages of the skin; the openings of the breathing chambers (Figs. 81, 82, 216, 223).

Dissect alcoholic specimens in a dish of weak alcohol or of water, and note the arrangement of the digestive and nervous systems.

Mollusca

Mussel

The river mussels may be kept in aquariums having two to four inches of sand or mud on the bottom.

Aquarium Study. — Study the movements of the animal; the opening and closing of the shell; the position and use of the foot; of the siphons; the sensitiveness of the siphonal tentacles; the incurrent and excurrent streams of water (Fig. 86).

Structure. — Examine a shell, noting the two similar valves; the hinge and hinge ligament; the hinge teeth (if present); the "epidermis," lines of growth, and nacre; the scars left by the muscles (Fig. 296).

Examine the soft part of the body, the mantle lobes; the gills; the body and the foot; the palpi and the mouth; the anal opening; the adductor, protractor, and retractor muscles.

Cut through the body lengthwise and trace the course of the alimentary canal. Endeavor to trace the parts of the nervous system; the cerebral and the visceral ganglia; the heart; the digestive gland (Figs. 244, 332). Make three or four cross sections from a specimen

hardened in formalin or alcohol and study the supra-branchial canal, gills, etc. (Fig. 275).

Examine the gills for eggs and young.

Land or Water Snail

Field or Aquarium Study.— Study its movements ; its mode of respiration ; its feeding ; the movements of the “rasp” ; the use of the “feelers” ; the manner in which the body is protruded from the shell and retracted.

Structure.— Compare its shell with that of the mussel. Note the whorls ; the lines of growth ; the attachment of the body to the shell (Fig. 297).

Remove the soft parts and study their structure, the digestive system (Fig. 227) ; the large liver ; the heart, the brain, and nervous system (Figs. 243, 331, 351). Note that the bodies of both these mollusks are unsegmented and are without appendages.

Snails kept in aquariums frequently attach their eggs to the sides of the jar or to water plants. The segmentation of the egg and the development of the larva may be studied with a low power or with a hand lens.

VERTEBRATES

Vertebrata

Fish

Aquarium Study.— Study living specimens in the aquarium, their movements of locomotion and of the various fins ; mouth, gill covers, and gills ; the eyes ; the method of feeding and of respiration ; the distribution of colored spots on the body ; the adaptation of shape to locomotion in the water ; test the use of each fin by binding them separately to the body by means of rubber bands slipped on over the fish’s head.

Structure.— On a dead specimen note the bilateral

symmetry; the head; the absence of a neck; the body and scales; the position and structure of the fins; the shape and structure of the mouth; the teeth; nostrils; tongue; gills; the lateral line; microscopic structure of scales and gills (Figs. 119, 320).

Dissect away the skin from one side and study the arrangement of the muscles.

Cut open a specimen and study the position and relation of the internal organs; the peritoneum; the digestive (Fig. 246), circulatory, and reproductive systems (Figs. 268, 269, 272); the structure of the heart; open the skull and examine the brain and the principal nerves arising from it (Fig. 336). Remove, by boiling, the flesh from the skeleton, and study the structure of the latter (Fig. 309).

Make a microscopic examination of the blood (Fig. 262).

Obtain (from one of the state hatcheries, if necessary) a series of living eggs and embryos, and study the development of the fish.

If opportunity offers, a fish market may be visited and an examination made of the various kinds of food fishes.

Frog

Vivarium and Aquarium Study. — Keep live specimens in aquarium jars or in boxes containing damp moss. Study the manner in which the frog creeps, leaps, swims, breathes, moves, and closes its eyes, catches flies; the position of the body at rest; with a thermometer try to get the natural temperature of the body.

Structure. — In a recently killed specimen note the color and structure of the skin, the position of eyes, ears, nostrils, lips, the position and arrangement of the lips and the teeth, the shape and mode of attachment of

the tongue; the sticky saliva and its use; the absence of a neck.

Dissect away the skin and study the shape and attachments of the underlying muscles. Open the abdomen and study the arrangement of the internal organs, the digestive, circulatory, respiratory, excretory, and reproductive systems (Figs. 273, 282); the structure of the heart. Open the skull and examine the brain (Fig. 337); trace the course of the principal nerves. Study the principal parts of the skeletal system and compare with that of the fish (Fig. 284). Examine the circulation of the blood as seen in the web of the foot (Fig. 263). Study the corpuscles in a drop of fresh blood (Figs. 260, 261).

Collect the eggs of frogs or toads in the spring, keep them in an aquarium, and watch the development of the tadpole. Have a series of tadpoles showing the gradual metamorphosis into the adult stage.

Draw attention to the changes of structural adaptation necessitated by the change from the aquatic to the aërial mode of life.

Turtle

Water or land turtles may be used, and may be kept alive indefinitely in a damp box in the laboratory.

Field, Vivarium, and Aquarium Study. — On some of the field excursions look for turtles in their native haunts, and learn as much as possible of their habits. In the laboratory note how the turtle walks, its clumsy motions, rate of speed; the motions of and positions taken by its head, legs, tail; movements of the eyelids, nostrils; the respiratory movements. Put the turtle into water and watch its movements when swimming and diving.

Structure. — Study the external covering, its structure, color, and modifications on the body, head, legs, and tail;

compare with the fish and the frog; the head, its shape and various parts composing it, the jaws, eyes, nostrils; note the absence of teeth; the tongue.

Remove the lower half of the shell and study the internal organs composing the digestive, circulatory, reproductive, and excretory systems; compare the structure of the heart with that of the fish and the frog (Fig. 273).

On a skeleton note the various parts which are attached to the shell; the skull and neck; the hyoid apparatus, the structure of the limbs and tail; compare the hyoid apparatus and the ribs with those of the frog (Fig. 312).

If eggs can be obtained, note the shape, structure of the shell, and the stages of development of the young.

Bird

Sparrows or pigeons may be used.

Field Study. — Note its general mode of life, whether solitary or gregarious; relations to other birds and to man; its manner of flight and of walking; feeding habits; size, shape, and coloration of the body; variations in coloration at different seasons of the year; position and structure of the nest, number, shape, size, and color of eggs, number of broods each year, season when broods are produced, and number of young in each brood; enemies; song; if a living specimen can be obtained, test the body temperature with a thermometer.

Structure. — With a recently killed specimen, study the shape of the body, the direction of its axis; the position and mobility of the head, wings, legs, and tail; the distribution of the various feathers, their structure (Figs. 139, 302). Remove the latter and note the feather tracts and the skin. Study the shape and structure of

the head, the beak, eyes, nostrils, and ears; compare with the turtle. Examine the wings and legs, noting the direction and movements of the various segments; the structure and movements of the parts of the foot; the position of the principal muscles, their uses.

Open the body and study the digestive, circulatory, respiratory, and reproductive systems (Figs. 248, 273); the air spaces among the muscles; the structure of the heart and brain as compared with the vertebrates previously studied (Fig. 338); the microscopic appearance of the blood corpuscles (Fig. 262).

Prepare or purchase a skeleton and study the arrangement of its various parts and the structure of the different bones, comparing with the fish, frog, and turtle (Fig. 313).

Study the structure of the egg (Fig. 358), and the development of the young (a convenient and satisfactory substitute is the hen's egg) (Figs. 365, 366).

Draw attention to the economic value of the bird studied.

Mammal

The cat or rabbit may be used.

Laboratory Study.—Study the motions of the animal as it walks, runs, leaps, its position when at rest; food and mode of feeding; respiratory movements; motions of head, legs, tail, ears, eyes; mode of cleaning its fur; body temperature; protective coloration.

Structure.—On a recently killed specimen note the general shape of the body and direction of its axis; the position and mode of attachment of the appendages; the hairy covering, the groups of specialized hairs in certain positions, the microscopic appearance of hair; the mobility of the skin; its firmer attachment in certain places, compare with the external covering of fish, frog, turtle, and bird. Study the shape and structure

of the head, the position and structure of ears, eyes, nostrils, and mouth.

Remove the skin from the body and study the position and attachment of the more important muscles, their uses. Open the body and examine the organs composing the digestive, circulatory, respiratory (Fig. 283), excretory, and reproductive systems (Fig. 250). Note the position and structure of the teeth and their fitness to masticate the special kind of food the animal eats; the surface of the tongue and its adaptation as an organ for cleaning the fur; compare the heart and brain (Fig. 339), and the microscopic appearance of the blood corpuscles with those of other vertebrates examined (Fig. 259).

Trace the course of some of the principal blood vessels and nerves.

Examine a skeleton and compare with that of the other vertebrates studied (Fig. 303).

A series of preparations of fetal kittens or rabbits may be examined.

CHAPTER II

THE CLASSIFICATION OF ANIMALS

THE Kingdom of Nature is a literal Kingdom. Order and beauty, law and dependence, are seen everywhere. Amidst the great diversity of the forms of life, there is unity; and this suggests that there is one general plan, but carried out in a variety of ways.

Naturalists have ceased to believe that each animal or group is a distinct, circumscribed idea. "Every animal has a something in common with all its fellows: much with many of them; more with a few; and, usually, so much with several, that it differs but little from them." The object of classification is to bring together the like, and to separate the unlike. But how shall this be done? To arrange a library in alphabetical order, or according to size, binding, date, or language, would be unsatisfactory. We must be guided by some essential character. We must decide whether a book is poetry or prose; if poetry, whether dramatic, epic, lyric, or satiric; if prose, whether history, philosophy, theology, philology, science, fiction, or essay. The more we subdivide these groups, the more difficult the analysis.

A classification of animals, founded on external resemblances—as size, color, or adaptation to similar habits of life—would be worthless. It would bring together fishes and whales, birds and bats, worms and eels. Nor should it be based on any one character, as the quality of the blood, structure of the heart, development of the brain, embryo life, etc.; for no character is

of the same value in every tribe. *A natural classification must rest on those prevailing characters which are the most constant.*⁴ And such a classification can not be linear. It is impossible to arrange all animal forms from the sponge to man in a single line, like the steps of a ladder, according to rank. Nature passes in so many ways from one type to another, and so multiplied are the relations between animals, that one series is out of the question. There is a number of series, and series within series, sometimes proceeding in parallel lines, but more often divergent. The animals arrange themselves in radiating groups, each group being connected, not with two groups merely, one above and the other below, but with several. Life has been likened to a great tree with countless branches spreading widely from a common trunk, and deriving their origin from a common root; branches bearing all manner of flowers, every fashion of leaves, and all kinds of fruit, and these for every use.

The groups into which we are able to cast the various forms of animal development are very unequal and dissimilar. We must remember that a genus, order, or class is not of the same value throughout the kingdom. Moreover, each division is allied to others in different degrees — the distance between any two being the measure of that affinity. The lines between some are sharp and clear, between others indefinite. Like the islands of an archipelago, some groups merge into one another through connecting reefs, others are sharply separated by unfathomable seas, yet all have one common basis. Links have been found revealing a relationship, near or distant, even between animals whose forms are very unlike. There are fishes (*Dipnoi*) with some amphibian characters, and fishlike amphibians (*Axolotl*). The extinct ichthyosaurus was a lizard with fish charac-

teristics. Birds seem isolated, but they are closely connected with reptiles by fossil forms. Even the great gap in the animal kingdom—that separating vertebrates and invertebrates—is partially bridged on the one side by amphioxus, and on the other by balanoglossus (a wormlike animal) and the tunicates.

We have, then, groups subordinate to groups, and interlocking, but not representing so many successive degrees of organization. For, as already intimated, complication of structure does not rise in continuous gradation from one group to another. Every type starts at a lower point than that at which the preceding class closes; so that the lines overlap. While one class, as a whole, is higher than another, some members of the higher class may be inferior to some members of the lower one. Thus, certain starfishes are structurally more complex than certain mollusks; and the nautilus is above the worm. The groups coalesce by their inferior or less specialized members; *e.g.*, the fishes do not graduate into amphibians through their highest forms, but the two come closest together low down in the scale. Among the craniate animals the lines of descent of the various classes may be represented as diverging and ascending from a point occupied by a fishlike ancestor.

A number of animals may, therefore, have the same grade of development, but conform to entirely different *types*. While a fundamental unity underlies the whole animal kingdom, suggesting a common starting point, we recognize several distinct plans of structure.⁵ Animals like the amœba, with no cellular tissues and no true eggs, form the branch *Protozoa*. Animals like the sponge, with independent cells, one excurrent and many incurrent openings, form the branch *Porifera*. Animals like the coral, unlike all others, have an alimentary canal

but no body cavity, have no separate nervous and vascular regions, and the parts of the body radiate from a center. Such form a branch called *Cœlenterata*. Animals like the starfish, having also a radiating body, but a closed alimentary canal, and a distinct symmetrical nervous system, constitute the branch *Echinodermata*.⁶ Animals like the angleworm, bilaterally symmetrical, one-jointed, or composed of joints following each other from front to rear, with no jointed limbs, constitute the branch *Annulata*. Animals like the snail, with a soft, unjointed body, a mantle, a foot, a two or three chambered heart, and a nervous system in the form of a ring around the gullet, constitute the branch *Mollusca*. Animals like the bee, with a jointed body and jointed limbs, form the branch *Arthropoda*. Animals like the ox, having a double nervous system, one (the sympathetic) lying on the upper side of the alimentary canal, the other and main part (spinal) lying along the back, and completely shut off from the other organs by a partition of bone or gristle, known as the "vertebral column," and having limbs, never more than four, always on the side opposite the great nervous cord, constitute the branch *Vertebrata*.

Comparing these great divisions, we see that the vertebrates differ from all the others chiefly in having a double body cavity and a double nervous system, the latter lying above the alimentary canal; while invertebrates have one cavity and one nervous system, the latter being placed mainly below the alimentary canal.

But there are types within types. Thus, there are five modifications of the vertebrate type — fish, amphibian, reptile, bird, and mammal; and these are again divided and subdivided, for mammals, *e.g.*, differ among themselves. So that in the end we have a constellation of groups within groups, founded on peculiar characters

of less and less importance, as we descend from the general to the special.

Individuals are the units of the Animal Creation. An animal existence, complete in all its parts, is an individual, whether separate, as man, or living in a community, as the coral.⁷

Species is the smallest group of individuals which can be defined by distinct characteristics, and which is separated by a gap from all other like groups. A well-marked subdivision of a species is called a *variety*. Crosses between species are called *hybrids*, as the mule.

Genus is a group of species having the same essential structure. Thus, the closely allied species cat, tiger, and lion belong to one genus.

Family, or **Tribe**, is a group of genera having a similar form. Thus, the dogs and foxes belong to different genera, but betray a family likeness.

Order is a group of families, or genera, related to one another by a common structure. Cats, dogs, hyenas, and bears are linked together by important anatomical features; their teeth, stomachs, and claws show carnivorous habits.

Class is a still larger group, comprising all animals which agree simply in a special modification of the type to which they belong. Thus, fishes, amphibians, reptiles, birds, and mammals are so many aspects of the vertebrate type.

Branch is a primary division of the animal kingdom, which includes all animals formed upon one of the various types of structure; as vertebrate.

The branches are grouped into two great **Series** (Protozoa and Metazoa), according to their histological structure and mode of development.⁸

These terms were invented by Linnæus, except

Family, Branch, and Series. To Linnæus we are also indebted for a scientific method of naming animals. Thus, the dog, in Zoölogy, is called *Canis familiaris*, which is the union of a generic and a specific name, corresponding to the surname and the Christian name in George Washington, only the specific name comes last. It will be understood that these are abstract terms, expressing simply the relations of resemblance; there is no such *thing* as genus or species.

Classification is a process of comparison. He is the best naturalist who most readily and correctly recognizes likeness founded on structural characters. As it is easier to detect differences than resemblances, it is much easier to distinguish the class to which an animal belongs than the genus, and the genus than the species. In passing from species to classes, the characters of agreement become fewer and fewer, while the distinctions are more and more manifest; so that animals of the same class are more like than unlike, while members of distinct classes are more unlike than like.

To illustrate the method of zoölogical analysis by searching for affinities and differences, we will take an example suggested by Professor Agassiz. Suppose we see together a dog, a cat, a bear, a horse, a cow, and a deer. The first feature which strikes us as common to any two of them is the horn in the cow and the deer. But how shall we associate either of the others with these? We examine the teeth, and find those of the dog, the cat, and the bear sharp and cutting; while those of the cow, the deer, and the horse have flat surfaces, adapted to grinding and chewing, rather than to cutting and tearing. We compare these features of their structure with the habits of these animals, and find that the first are carnivorous — that they seize and tear their prey; while the others are herbivorous, or

grazing, animals, living only on vegetable substances, which they chew and grind. We compare, further, the horse and cow, and find that the horse has front teeth both in the upper and the lower jaw, while the cow has them only in the lower; and going still farther, and comparing the internal with the external features, we find this arrangement of the teeth in direct relation to the different structure of the stomach in the two animals—the cow having a stomach with four pouches, while the horse has a simple stomach. Comparing the cow and deer, we find the digestive apparatus the same in both; but though both have horns, those of the cow are hollow, and last through life; while those of the deer are solid, and are shed every year. Looking at the feet, we see that the herbivorous animals are hoofed; the carnivorous, clawed. The cow and deer have cloven feet, and are ruminants; the horse has a single hoof, and does not chew the cud. The dog and cat walk on the tips of their fingers and toes (digitigrade); the bear treads on the palms and soles (plantigrade). The claws of the cat are retractile; those of the dog and bear are fixed.

In this way we determine the exact place of each animal. The dog belongs to the kingdom *Animalia*, branch *Vertebrata*, class *Mammalia*, order *Carnivora*, family *Canidæ*, genus *Canis*, species *familiaris*, variety *hound* (it may be), and its individual name, perhaps, is "Rover." The cat differs in belonging to the family *Felidæ*, genus *Felis*, species *domestica*. The bear belongs to the family *Ursidæ*, genus *Ursus*, and species *horribilis*, if the grizzly is meant. The horse, cow, and hog belong to the order *Ungulata*; but the horse is of the family *Equidæ*, genus *Equus*, species *caballus*; the cow is of the family *Bovidæ*, genus *Bos*, species *taurus*; the pig is of the family *Suidæ*, genus *Sus*, species *scrofa*, if the domestic pig is meant.

The diagram on the opposite page roughly represents (for the relations of animals can not be expressed on a plane surface) the relative positions of the branches and classes according to affinity and rank.*

SERIES I. — PROTOZOA

Animals whose bodies consist of a single cell, the process of reproduction being by division or by budding, but never by means of true eggs.

Branch I. — PROTOZOA

In structure the Protozoa are the simplest of animals, consisting of only a single cell. They are microscopic in size and aquatic in habit, though in certain stages of their lives (encystation) many of them may endure dryness for weeks or months. Their bodies consist mainly or wholly of protoplasm, which may or may not be covered by a cuticle or by a shell-like excretion of lime, chitin, or flint, or inclose spicules of the latter substance. The various individuals may live separately as single, independent organisms, or they may be organically joined together in clusters called colonies. They exhibit all the essential functions of life — nutrition, growth, nervous properties, and reproduction. They feed upon minute algæ, bacteria, vegetable débris, and upon other microscopic animals. Some forms are parasitic. It has been shown by experiment that many species are sensitive to changes in the amount of illumination to which their bodies are exposed and to various colors of light; that they are attracted or re-

* The student should master the distinctions between the great groups, or classes, before proceeding to a minuter classification. "The essential matter, in the first place," says Huxley, "is to be quite clear about the different classes, and to have a distinct knowledge of all the sharply definable modifications of animal structure which are discernible in the Animal Kingdom."

	Aves.	Mammalia.
	Reptilia.	
	CHORDATA.	
	Pisces, Amphibia.	
	Acrania, Cyclostomata.	
	Adelochorda, Urochorda.	
	Insecta.	
	Myriapoda, Arachnida.	
	ARTHROPODA.	
	Onycophora, Crustacea.	
	Cephalopoda.	
	Gastropoda.	
	MOLLUSCA.	
	Pelecypoda, Amphineura.	
	ANNULATA.	
	MOLLUSCOIDA.	
	TROCHELMINTHES.	
	NEMATHELMINTHES.	
	PLATYHELMINTHES.	
	Crinoidea.	
	ECHINODERMATA.	
	Holothuroidea Ophiuroidea.	
	Echinoidea. Asteroidea.	
	Infusoria.	
	Mastigophora.	
	PROTOZOA.	
	Mycetozoa.	
	Sporozoa, Rhizopoda.	
	Actinozoa.	
	Ctenophora.	
	CŒLENTERATA.	
	Hydrozoa. Scyphozoa.	
	PORIFERA.	
	PROTOZOA.	
	METAZOA.	

pelled by the presence of different chemical substances in the water; and that they are sensitive to contact with foreign bodies and with one another. Thus it is proved that these simple organisms possess the rudiments of the nervous properties seen in the higher animals. Certain species contain a green coloring substance (hæmatochrome) which is chemically allied to the chlorophyll of plants. Others, again, pass through amœboid stages resembling similar phases in the development of some of the lowest plants. Because of these resemblances some of the Protozoa are almost indistinguishable from the lowest members of the plant kingdom (Protophyta).

On account of the apparent simplicity of their structure, it is difficult to select features by means of which the animals in this group may be classified. The difficulty is further increased by the fact that in the course of their development some forms pass through stages in which they resemble other species in the same branch. In every case, however, it is found that certain phases of their development predominate, and these well-marked phases permit of dividing the Protozoa into five classes.

CLASS I. — **Rhizopoda**

These are Protozoa which are predominantly amœboid in shape and which move by means of *pseudopodia*, as the slow-moving protrusions of the protoplasmic body substance are called (Figs. 1, 213). The body usually contains a nucleus and a contractile vacuole. The common amœba or proteus animalcule belongs in this class (Fig. 1). Some of the Rhizopods secrete shells of chitin (*Arcella*), or construct a covering made of particles of sand (*Diffugia*). Both of these organisms are found in fresh water in America. The most primitive representative of the group is *Protamœba*, in which

neither nucleus nor contractile vacuole has been discovered. *Pelomyxa*, a fresh-water form, may reach the size of eight millimeters (.3 of an inch) in diameter.

An amœba is a naked fresh-water Rhizopod, containing a nucleus and a contractile vacuole, the body sub-

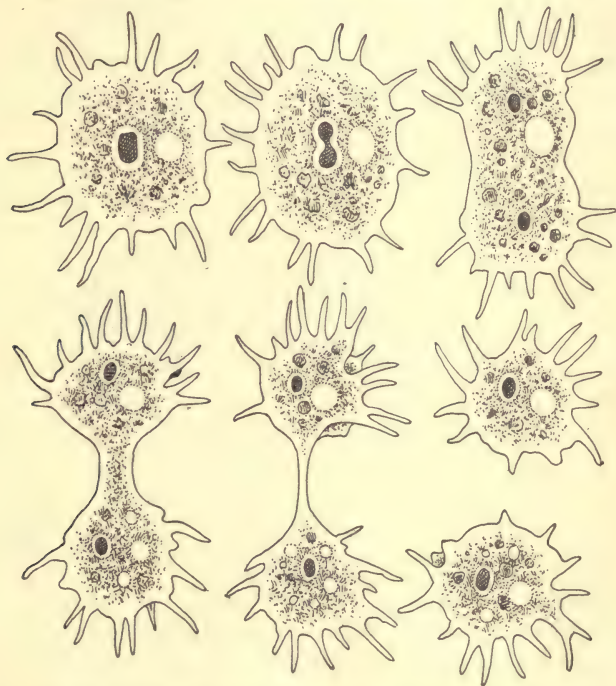


FIG. 1. — *Amœba*, showing the structure of the body and the changes which take place during division. The dark body in each figure is the nucleus ; the transparent circle, the contractile vacuole ; the protrusions of the body substance, pseudopodia ; the outer, clear portion of the body, the ectosarc ; the granular masses, food vacuoles. Much magnified.

stance consisting of two rather distinct layers, the outer being quite clear and transparent, while the inner is usually filled with granules and ingested particles. During movement the shape of the body is constantly changing, owing to the protrusion and withdrawal of the pseudo-

podia. Food is taken into the body at any point, there being no mouth.

A Foraminifer differs from an amœba in having an apparently simpler body, the protoplasm being without layers or cavity; its pseudopodia are long and threadlike, and may unite where they touch each other. It has the property of secreting an envelope, usually of carbonate of lime. The shell thus formed is sometimes of extraordinary complexity and singular beauty. In addition to the terminal aperture, it is generally perforated by

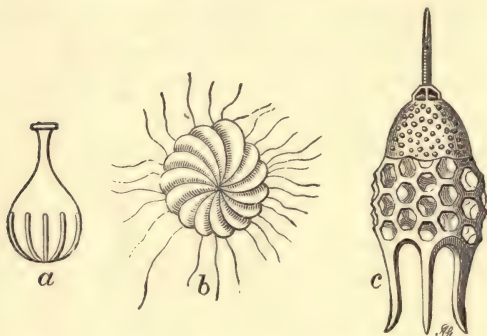


FIG. 2.—Rhizopods: *a*, shell of a monothalamous, or single-chambered, Foraminifer (*Lagena striata*); *b*, shell of a polythalamous, or many-chambered, Foraminifer (*Polystomella crispa*), with pseudopodia extended; *c*, shell of a Radiolarian, one of the Polycystines (*Podocyrthis schomburgkii*).

innumerable minute orifices (*foramina*) through which the animal protrudes its myriad of glairy, threadlike arms. The majority are compound, resembling chambered cells, formed by a process of budding, the new cells being added so as to make a straight series, a spiral, or a flat coil. As a rule, the many-chambered species have calcareous, perforated shells; and the one-chambered have an imperforated membranous, porcelainous, or arenaceous envelope. The former are marine. There are few parts of the ocean where these microscopic shells do not occur, and in astounding numbers.

A single ounce of sand from the Antilles was calculated to contain over three millions. The bottom of the ocean, up to about 50° on each side of the Equator, and at depths not greater than 2400 fathoms, is covered with the skeletons of these animals, which are constantly falling upon it (*Globigerina ooze*). Their remains constitute a great proportion of the so-called sand banks which block up many harbors. Yet they are descendants of an ancestry still more prolific, for the Foraminifera are among the most important rock-building animals. The chalk cliffs of England, the building stone of Paris, and the blocks in the Pyramids of Egypt are largely composed of extinct Foraminifers. Foraminifera are both marine and fresh-water, chiefly marine.

The sun animalcule (*Actinophrys sol*), one of the *Heli-ooza*, is common in the slime on the sides of aquaria. Its spherical body, composed of frothy protoplasm, bears numerous stiff radiating processes by means of which the animal moves about and captures its food.

A Radiolarian differs from a Foraminifer in secreting a siliceous, instead of a calcareous, shell, studded with radiating spines; and in the central part of the body is a perforated membranous sac containing a nucleus or, sometimes, several nuclei. The most of the protoplasm of the body lies outside the sac. Radiolarians are more minute than Foraminifera, but as widely diffused. They enter largely into the formation of some strata of the earth's crust, and abound especially in the rocks of Barbadoes and at Richmond, Va. The living forms are marine.

CLASS 2. — Mycetozoa

These organisms are frequently classified among the plants under the name of "slime molds." They consist of masses of protoplasm of various sizes and colors, and

are terrestrial in habit, being often found in summer slowly crawling upon stumps, logs, and leaves.

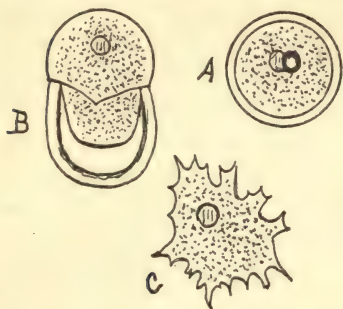


FIG. 3. — Germination of a spore of a Mycetozoon (*Trichia*), showing the development of the amœboid stage. Much magnified.

In their nonmotile stage of development they resemble the spore-bearing organs and spores of certain Fungi, but in their locomotor phase they exhibit the structure and physiology of amœboid and flagellate Protozoa, sometimes

forming large, multinucleated masses of protoplasm which crawl about and ingest solid food (Fig. 3).

CLASS 3. — Mastigophora

The distinctive character of the animals in this group is the presence of one or more *flagella*, long, whiplashlike threads of protoplasm used for locomotion and for obtaining food. Some kinds, like *Euglena* (Fig. 4), live as independent organisms, while others, as *Volvox* and *Dinobryon*, form colonies (Fig. 5). The latter two are of some sanitary importance, since either one, when present in large numbers in a water supply, is likely to cause unpleasant tastes and odors. *Noctiluca*, a marine form, is one of the causes of phosphorescence in the sea. Some of the higher kinds, e.g., *Codosiga* (Fig. 6), are interesting for the reason that they bear a peculiar struc-

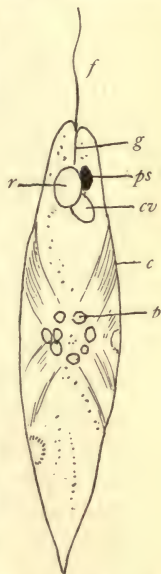


FIG. 4. — *Euglena*: *f*, flagellum; *g*, gullet; *ps*, pigment spot or "eye"; *cv*, contractile vacuole; *r*, reservoir; *p*, paramylum bodies; *c*, chlorophyll bodies. Much magnified.

ture, the so-called "collar," which is found practically nowhere else except on certain cells in sponges (Figs. 6, 14).

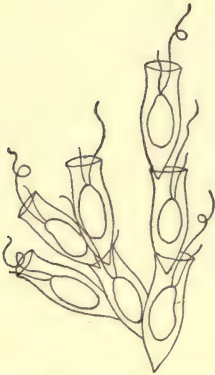


FIG. 5. — *Dinobryon*, portion of the motile colony showing zooids, each in its own lorica. Much magnified.

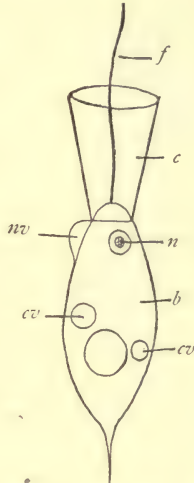


FIG. 6. — *Codosiga*: *f*, flagellum; *c*, "collar"; *b*, body; *n*, nucleus; *cv*, contractile vacuole; *nv*, nutritive vacuole. Much magnified.

CLASS 4. — Sporozoa

The Sporozoa are all parasitic, and are found in various parts of the bodies of fishes, frogs, turtles, insects, crustaceans, worms, and so on, some living in the digestive organs, others in glands, while still others penetrate into the muscle fibers of the infested animal (Fig. 7). They have no organs of locomotion, but move by wormlike contortions of the body. The protoplasmic body substance is covered by a cuticle, and contains a nucleus (Fig. 8). Liquid food is absorbed through the cuticle (Fig. 7).

Probably the parasite which causes malaria in man belongs in this group.

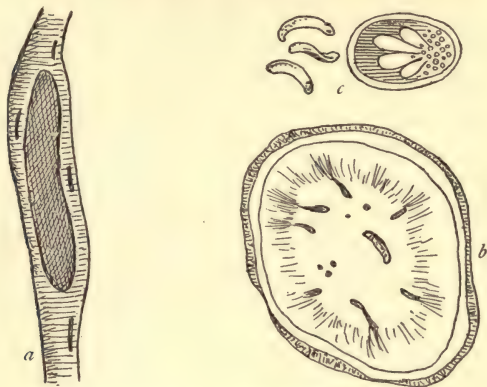


FIG. 7. — *Sporozoa*: *a*, embedded in the striated muscle fiber of the ox; *b*, *Gregarina* in the intestine of the beetle; *c*, cyst and young germs of *Klossia* from the snail. All much magnified.

Reproduction is by means of spores. The individuals become surrounded by a thickened covering or cyst secreted from their bodies. Within this cyst division into numerous smaller masses takes place. Each mass

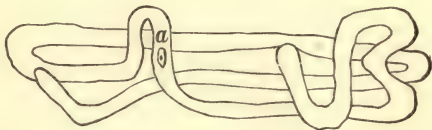


FIG. 8. — *Gregarina gigantea*, highly magnified: *a*, nucleus.

then secretes a thickened coat and becomes a spore. When mature, the protoplasmic mass within breaks through the wall of the cyst and enters the organ or animal in which the parasite reaches its adult condition (Fig. 7).

CLASS 5. — Infusoria

The name of this group is derived from the fact that the animals composing it are almost always found in infusions of vegetable substance. The characteristic feature of the group is the presence of fine, hair-like protrusions of the body substance, which more or less completely cover the animal, and which are called *cilia*. These are permanent structures in some forms (*Ciliata*), but are found only in the young condition of others (*Tentaculifera*), the adults developing tentacles (Fig. 12). Their bodies show a great variety of shapes, spherical, flattened, oval, cylindrical, conical, and so on. Some live as independent organisms, as *Paramecium* (Fig. 9); others are sedentary, being attached by a stalk, as *Vorticella* (Fig. 11); the trumpet animal (*Stentor*) can attach itself at will. *Epistylis* forms branching colonies. In some colonies the members are all alike in structure and function (*Carchesium*), while in others (*Zoothamnium*) the members which capture the food for the colony are plainly different in shape, size, and structure from those which produce the new colonies, the latter being mouthless, larger, and capable

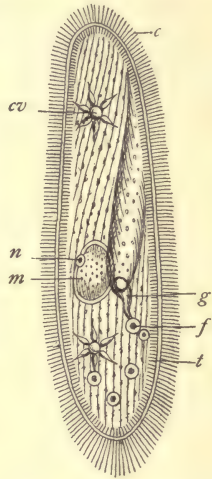


FIG. 9. — *Paramecium*, *c*, cilia; *g*, gullet; *f*, food vacuole; *t*, trichocysts; *cv*, contractile vacuole; *m*, macronucleus; *n*, micronucleus. Much magnified.

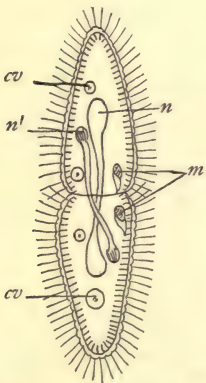


FIG. 10. — *Paramecium* in the process of fission: *m*, mouth; *cv*, contractile vacuole; *n*, macronucleus; *n'*, micronucleus. Much magnified.

(Fig. 9); others are sedentary, being attached by a stalk, as *Vorticella* (Fig. 11); the trumpet animal (*Stentor*) can attach itself at will. *Epistylis* forms branching colonies. In some colonies the members are all alike in structure and function (*Carchesium*), while in others (*Zoothamnium*) the members which capture the food for the colony are plainly different in shape, size, and structure from those which produce the new colonies, the latter being mouthless, larger, and capable

of freeing themselves from their stalk and swimming away to another place where the new colony is to be started. Thus there is shown among these simple organisms the differentiation of parts which is one of the characteristic features of the higher forms of animal life.

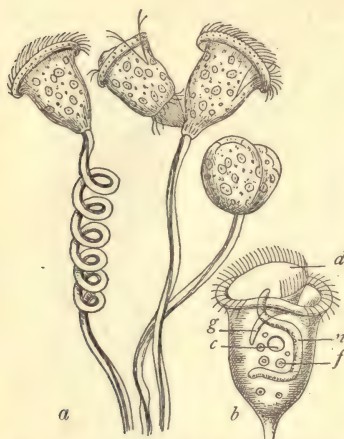


FIG. 11. — *Vorticella*: *a*, showing stages of fission, and *b*, internal structure; *d*, ciliated disk; *g*, gullet; *n*, nucleus; *c*, contractile vacuole; *f*, food vacuole. Much magnified.

The cilia are used for locomotion and for obtaining food, which, except in the parasitic species, is in the form of solid particles, consisting of bacteria and microscopic plants and animals, or of minute fragments of animal and vegetable material. All of the ciliata

which ingest solid food have a permanent mouth opening.

Tentaculifera suck through their tentacles the soft material composing the bodies of their prey. The cilia are uniformly arranged over the body, as in *Paramecium*, or are restricted to definite regions, as in *Vorticella*. In either case

there may be variations in their form, size, and function. Reproduction is by division and by budding,

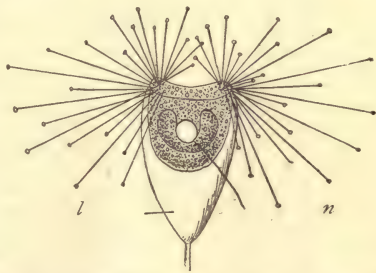


FIG. 12. — *Acineta*, animal in its lorica, *l*, showing suctorial tentacles and nucleus, *n*, with contractile vacuole. Only a small part of the stalk is shown. Magnified.

spore formation being exceptional. It has been estimated that by self-division a *Paramecium* may give rise to 1,364,000 in forty-two days (Figs. 10, 11).

SERIES II. — METAZOA

The Metazoa include all those animals whose bodies are multicellular, which reproduce by true eggs and spermatozoa. This series includes eleven of the branches of the animal kingdom.

Branch II. — PORIFERA

The position of the sponges has been much disputed. At first they were thought to be on the border line between animals and plants, and were assigned by some to the animals and by others to the vegetables. Later, and up to very recent years, they were assigned to the Protozoa. The discovery of their mode of reproduction and development has determined that they belong to the Metazoa.

Simple sponges, like *Grantia* (Fig. 13), are somewhat vase-shaped in outline, and have a single central cavity communicating with the outside through an opening called the *osculum*. The wall of the body is pierced by numerous fine canals which communicate more or less directly with the central cavity on the one hand and with the exterior on the other. There is no body cavity. The body wall is composed of the skeleton, together with the cellular elements forming the "flesh." The sur-

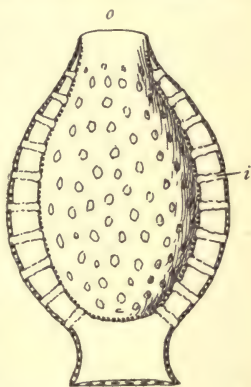


FIG. 13. — Diagram of a simple sponge: *i*, inhalant opening; *o*, exhalant opening or *osculum*.

face of the body is covered by a single layer of flattened cells forming the *ectoderm*. The canals are more or less completely lined with a layer of cells, each of which is provided with a *flagellum*, by means of which water is propelled through the canals toward the central cavity. Between these two layers is a mass of amœboid and other cells which compose the *mesoderm*, and in which the skeleton, or framework, of the sponge is developed. The skeleton may be composed of flexible

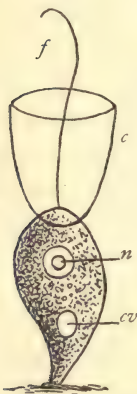


FIG. 14. — "Collar cell" from *Grantia*, showing flagellum, *f*; "collar," *c*; nucleus, *n*; contractile vacuole, *cv*. Much magnified.

fibers of *spongin*, as in the toilet sponge; or of spongin fibers together with spicules of calcareous matter, as in *Grantia*; or of siliceous spicules alone, as in the fresh-water sponge (*Spongilla* and *Myenia*) and Venus's flower basket (*Euplectella*); or of spicules of carbonate of lime and so on, while a few have no skeleton at all.

The flagellate cells are peculiar, in that they have an upgrowth on their free end, formed by a delicate expansion of the cell substance, and having the shape of a broad collar surrounding the base of the flagellum, whence their name of "collar cell" (Fig. 14).

The water flowing in through the canals bears with it the small particles of organic material upon which the sponge feeds, the particles being captured apparently by the collar cells as well as by the amœboid cells. The same currents of water serve also for respiration. Reproduction is by means of eggs and by budding, the latter process giving rise to a group of connected sponges. The young larval sponge which develops from the fertilized egg is provided with cilia, by means of which it can swim around

for a time. Later, it comes to rest, attaches itself to some support, and develops into the adult form which is

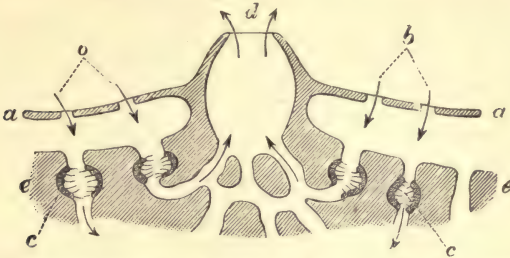


FIG. 15. — Hypothetical Section of a Sponge : *a*, superficial layer ; *b*, inhalant pores ; *c*, ciliated chambers ; *d*, exhalant aperture, or osculum ; *e*, deeper substance of the Sponge.

never capable of locomotion. The fresh-water sponges also multiply by means of *gemmules*, which are small,

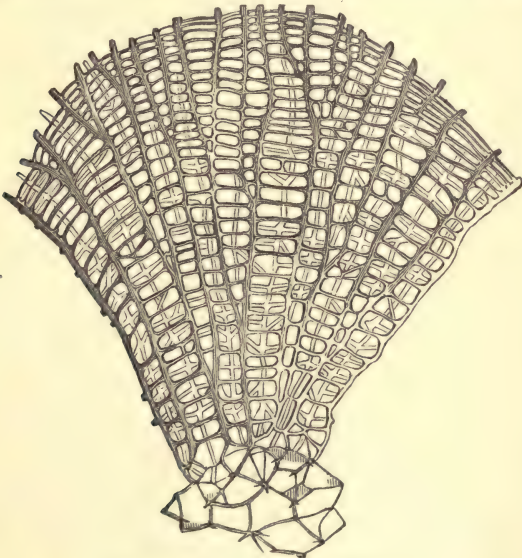


FIG. 16. — Skeleton of a Horny Sponge.

seedlike bodies to be found in the sponge in the fall. Each consists of a hard coating surrounding a mass of

cells and food substance. These gemmules survive the winter, and in the spring the cellular contents come out and develop into a sponge.

The sponge individual contains one exhalant orifice (osculum), with the channels leading into it. An ordinary bathing sponge constitutes a colony of such individuals, which are not definitely marked off from each other. Some other sponges have only one osculum, and such are a single individual, *e.g.* *Grantia*.

Excepting a few small fresh-water species (as *Spongilla*), sponges are marine. In the former, the cellular part is greenish, containing chlorophyll; in the latter, it is brown, red, or purple. In preparing the sponge of commerce, this is rotted by exposure, and washed out. The best fishing grounds are the eastern end of the Mediterranean and around the Bahama Islands.

Branch III. — CŒLENTERATA

In the animals comprising this group, the body cavity is not distinctly separated from the digestive cavity. The cœlenterates are almost wholly marine forms, — hydroids, corals, sea anemones and jellyfishes, — but there are a few which, like *Hydra*, live in fresh water. The body is usually radially symmetrical and shows three more or less definite cell layers, the *ectoderm* on the outer surface, the *endoderm* lining the inner cavities, with the *mesoderm*, or middle layer, between the others. In hydra and the hydroids the mesoderm is reduced to a mere film, but in the jellyfishes and sea anemones it forms a large part of the body. A characteristic feature is the presence of the stinging cells, or *nematocysts*, which are almost invariably to be found except in one group, — *Ctenophora*, — where they are replaced by adhesive cells.

This branch consists of two rather divergent forms, represented on the one hand by the sedentary type (hydroid), and on the other by the free-swimming type (jellyfish). These two forms may occur during the course of development of one individual, thus illustrating the phenomenon of "alternation of generations." Many of the members of the group are soft-bodied, while others secrete calcareous material forming coral.

All of the cœlenterates multiply by means of eggs and sperm cells, and all, except the *Ctenophora*, by budding as well, the latter method resulting in the formation of colonies in which the various members often differ greatly in form and in function.

The animals in this group are carnivorous, feeding mainly on small organisms, although the sea anemone can engulf masses of considerable size.

There are four classes :—

- Class 1. Hydrozoa, represented by hydra and the hydroids.
- Class 2. Scyphozoa, containing the large jellyfishes, for example, *Aurelia*.
- Class 3. Actinozoa, including the sea anemone and the corals.
- Class 4. Ctenophora, including the jellyfishes which have comblike swimming organs.

CLASS I. — Hydrozoa

In these cœlenterates the body is a simple tube, or cavity, in which there is a single aperture, the mouth. The nervous system is slightly developed. Such are fresh-water hydras and the oceanic hydroids (*Eucope*).

The body of the hydra is tubular, soft, and sensitive, of a greenish or brownish color, and seldom over half an inch long. It is found spontaneously attached by

one end to submerged plants, while the free end contains the orifice, or mouth, crowned with tentacles, by which the creature feeds and creeps. The body wall consists of two cellular layers — ectoderm and endoderm. These surround a central cavity with one opening. The animal may be compared to a bag with

a two-layered wall, and with tentacles around the opening. It buds, and also reproduces by eggs. The buds, when adult, become detached from the parent (Figs. 17, 18).

In most of the other Hydrozoa the colony is permanent, and supported by a horny skeleton. There are two kinds of Polyps in each colony, one for feeding and the other for reproduction (Fig. 20). Sometimes the

reproductive Polyps are separated from the stock in the form of little jellyfishes, and are then called medusæ (Figs. 20 *m*, 21). Belonging to this class are *Hydractinia*, found on the shells inhabited by the hermit crab; the elk-horn coral (*Millepora*); and the beautiful Portuguese man-of-war, consisting of a bladder-like float from the bottom of which depend tentacles many feet in length and several kinds of polyps, the tentacles being covered with stinging cells, which aid in capturing the prey and in defending the colony.



FIG. 17. — Hydra : 2, with tentacles fully extended; 3, creeping; 4, with ingested prey; 5, budding.

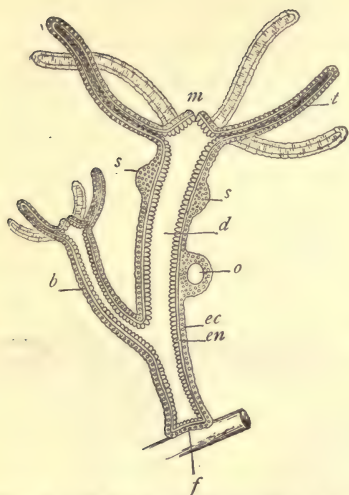


FIG. 18. — Hydra: longitudinal section of animal showing *m*, mouth; *t*, tentacle; *d*, digestive cavity; *b*, bud; *s*, spermary; *o*, ovary; *ec*, ectoderm; *en*, endoderm. Magnified.

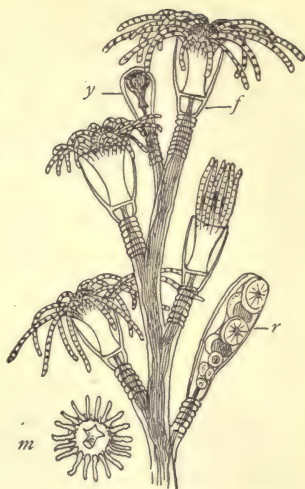


FIG. 20. — Campanularian hydroid: portion of colony, showing nutritive zooids, *f*; reproductive zooid, *r*; young zooid, *y*; and medusa, *m*. Magnified.



FIG. 19. — Hydroid (*Sertularia*) growing on a shell.

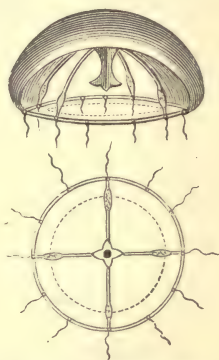


FIG. 21. — A Medusa, seen in profile and from below, showing central manubrium, radiating and marginal canals and tentacles.

CLASS 2. — Scyphozoa

These are jellyfishes which are characterized mainly by having reproductive glands which discharge their contents into the stomach whence the reproductive cells make their way out through the mouth, by having the gastric cavity much branched and ramifying through the gelatinous body, and by the presence of filaments projecting into the gastric cavity.



FIG. 22 — Jellyfish (*Pelagia noctiluca*). Mediterranean.



FIG. 23. — Portuguese Man-of-war (*Physalia*), $\frac{1}{2}$ natural size. Tropical Atlantic.

The jellyfish has a soft, gelatinous, semitransparent, umbrella-shaped body, with tubes radiating from the central digestive cavity to the circumference, and with the margin fringed with tentacles, which are furnished

with stinging thread cells. The radiating parts are in multiples of four. Around the rim are minute colored spots, the "eye specks." In fine weather, these "sea blubbers" are seen floating on the sea, mouth downward, moving about by flapping their sides, like the opening and shutting of an umbrella, with great regularity. They are frequently phosphorescent when disturbed. Some are quite small, resembling little glass bells; the common *Aurelia* is over a foot in diameter when full-grown; while the *Cyanea*, the giant among jellyfishes, sometimes measures eight feet in diameter, with tentacles more than one hundred feet long. The tissues are so watery that, when dried, nothing is left but a film of membrane weighing only a few grains.

The two common types are *Lucernaria* and *Aurelia*. The former is the Umbrella-acaleph and has a short pedicel on the back for voluntary attachment;

tentacles disposed in eight groups around the margin, the eight points alternating with the four partitions of the body cavity and the four corners of the

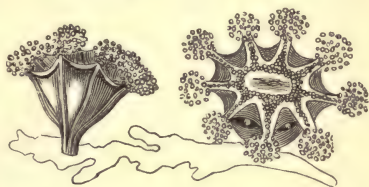


FIG. 24. — *Lucernaria auricula* attached to a piece of seaweed; natural size. The one on the right is abnormal, having a ninth tuft of tentacles.

mouth; not less than eight radiating canals, and no membranous veil. The common species on the Atlantic shore, generally found attached to eelgrass, is an inch in diameter, of a green color. *Aurelia*, the ordinary jellyfish, is free and oceanic. It differs from the *Lucernaria* in its usually larger size and solid disk, and in having four radiating canals, which ramify and open into a circular vessel which runs around the margin of the disk.⁹

CLASS 3. — Actinozoa

These marine animals, which by their gay tentacles convert the bed of the ocean into a flower garden, or by their secretions build up coral islands, have a body like a cylindrical gelatinous bag. One end, the base, is usually attached; the other has the mouth in the center, surrounded by numerous hollow tentacles, which are covered with nettling lasso cells. This upper edge is turned in so as to form a sac within a sac, like the neck of a bottle

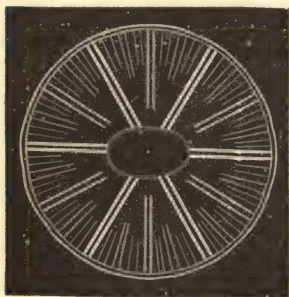


FIG. 25. — Horizontal Section of Actinia through the stomach, showing septa or mesenteries, and compartments.

turned outside in. The inner sac, which is the digestive cavity, does not reach the bottom, but opens into the

general body cavity (Fig. 236).¹⁰ The space between these two concentric tubes is divided by a series of vertical partitions or mesenteries, some of which extend from the body wall to the digestive sac, but others fall short of it. Instead, therefore, of the radiating tubes of the Scyphozoan, there are radiating

spaces. No members of this class are microscopic. All are long-lived compared with the Hydrozoa, living for



FIG. 26. — Actinia expanded, seen from above, showing mouth.

several years. One kept in an aquarium in England lived to be more than sixty years old.

There are two subclasses : —

1. Zoantharia, including the sea anemones and the stony corals, and,

2. Alcyonaria, to which belong the organ-pipe coral (*Tubipora*), sea fan (*Gorgonia*), the precious red coral (*Corallium*), and the sea pen (*Pennatula*).

Zoantharia usually have numerous tentacles, generally arranged in multiples of five or six, the tentacles being unbranched and hollow, while in the Alcyonaria the tentacles are finely branched and are always eight in number.

Zoantharia.—The best-known representative of this group is the *Metridium*, or sea anemone. It usually leads a solitary life, though frequently several are found together, some of which have arisen as buds from the others. It is capable of a slow locomotion. Muscular fibers run around the body, and others cross these at right angles. The tentacles, which often number over two hundred, and the partitions, which are in reality double, are in multiples of six. At night, or when alarmed, the tentacles are drawn in, and the aperture firmly closed, so that the animal looks like a rounded lump of fleshy substance plastered on the rock. It feeds on crabs and mollusks. It abounds on every shore, especially of tropical seas. The size varies from one eighth of an inch to a foot in diameter (Fig. 236).

Alcyonaria.—The most of the animals in this group grow in branching colonies, the axis consisting of a horny substance covered with flesh in which spicules of lime are found. The polyps are usually small. The sea pen (*Pennatula*) grows with one end embedded in the mud and sand of the sea bottom. In *Gorgonia*, the sea fan, the branches arise in the same

vertical plane and unite to form a beautiful network (Fig. 35).

Coral. — The majority of Actinozoa secrete a calcareous or horny framework called "coral." With few exceptions, they are fixed and composite, living in colonies

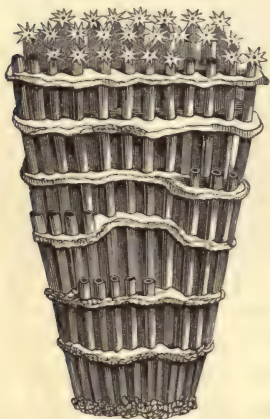


FIG. 27. — Organ-pipe coral (*Tubipora musica*). Indian Ocean.

formed by a continuous process of budding. Their structures take a variety of shapes; often domelike, but often resembling shrubbery and clusters of leaves. The members of a coral community are organically connected; each feeds himself, yet is not independent of the rest. The compound mass is "like a living sheet of animal matter, fed and nourished by numerous mouths and as many stomachs."

Life and death go on together, the old polyps dying below as new ones are developed above. The living part of an *Astræa* is only half an inch thick. The growth of the branching *Madrepora* is about three inches a year. The colors of the coral polyps are brilliant and varied, being green, purple, pink, or brown. The organ-pipe coral has green polyps and crimson skeleton, while the precious coral (*Corallium*) has white polyps and a bright red axis. Another kind is bright blue. The usual size varies from that of a pin's head to half an inch, but the mushroom coral (which is a single individual) may be a foot in diameter.

Corals are of two kinds: those deposited within the tissues of the animal (*sclerodermic*), and those secreted by the outer surface at the foot of the polyp (*sclerobasic*). The polyps producing the former are actinoid,

resembling the *Actinia* in structure.¹¹ The skeleton of a single polyp (called *corallite*, Fig. 292) is a copy of the animal, except the stomach and tentacles, the earthy matter being secreted within the outer wall and between each pair of partitions. So that a corallite is a short tube with vertical septa radiating toward the center.¹²

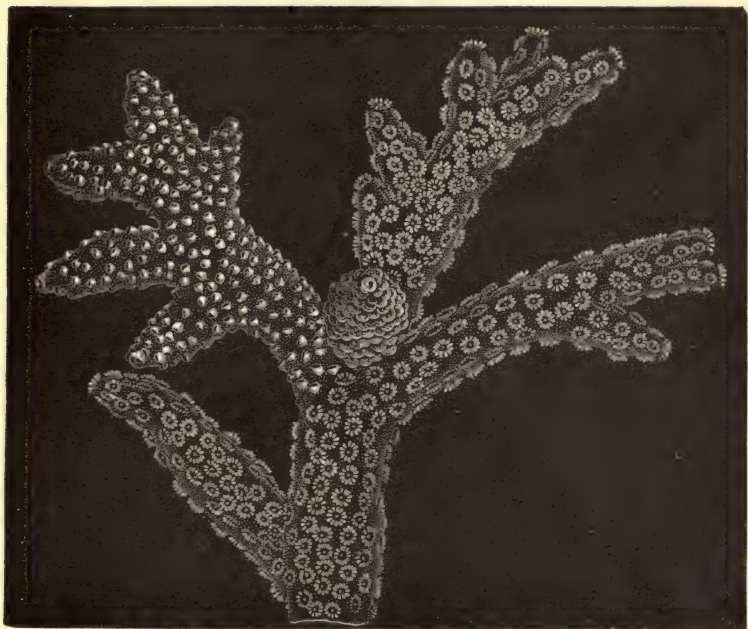


FIG. 28. — *Madrepora aspera*, living and expanded ; natural size. Pacific.

A sclerobasic coral is a true exoskeleton, and is distinguished by being smooth and solid. The polyps, having eight fringed tentacles, are situated on the outside of this as a common axis, and are connected together by the fleshy *cœnosarc* covering the coral.

(1) **Sclerodermic Corals.**—*Astræa* is a hemispherical mass covered with large cells. *Meandrina*, or “brain coral,”

is also globular; but the mouths of the polyps open into each other, forming furrows. *Fungia*, or "mushroom coral," is disk-shaped, and differs from other kinds in

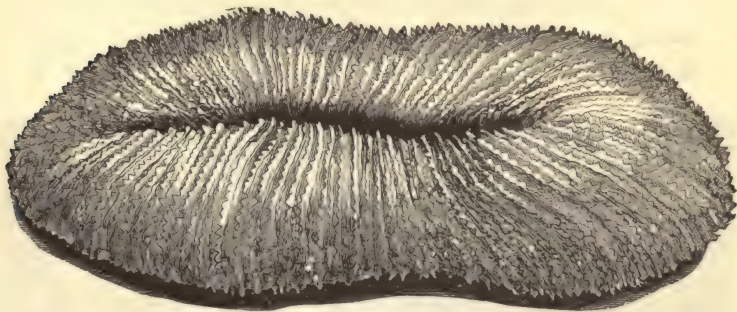


FIG. 29. — *Ctenactis echinata*, or "Mushroom Coral": one fourth natural size. Pacific.

being the secretion of a single gigantic polyp, and in not being fixed. *Madrepora* is neatly branched, with

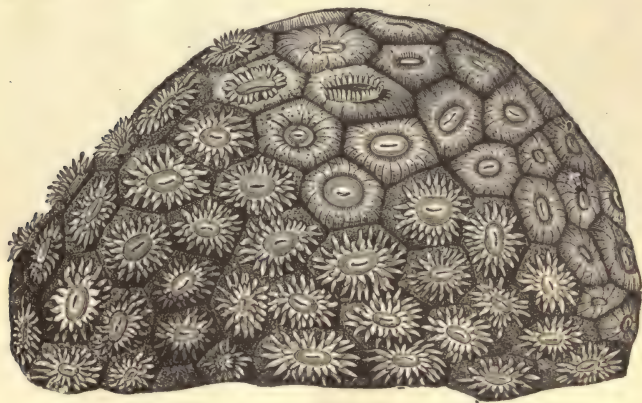


FIG. 30. — *Astræa pallida*, living colony; natural size. Feejee Islands.

pointed extremities, each ending in a small cell about a line in diameter. *Porites*, or "sponge coral," is also branching, but the ends are blunt, and the surface com-

paratively smooth. *Tubipora*, or "organ-pipe coral," consists of smooth red tubes connected at intervals by cross plates. The *Astræa*, *Meandrina*, *Madrepora*, and *Porites* are the chief reef-forming corals. They will not live in waters whose mean temperature in the coldest month is below 68° Fahr., nor at greater depth than about twenty fathoms. The most luxuriant reefs



FIG. 31. — *Diploria cerebriformis*, or "Brain Coral"; one half natural size. Bermudas.

are in the central and western Pacific and around the West Indies.

A coral reef is formed by many corals growing together. It is to the single coral stock as a forest is to a tree. The main kinds of reefs are *fringing*, where the reef is close to the shore; *barrier*, where there is a channel between reef and shore; *encircling*, where there is a small island inside of a large reef; and *coral islands*,

or *atolls*, where there is simply a reef with no land inside of it. The Great Barrier Reef off the east coast of



FIG. 32. — *Astræa rotulosa*. West Indies.

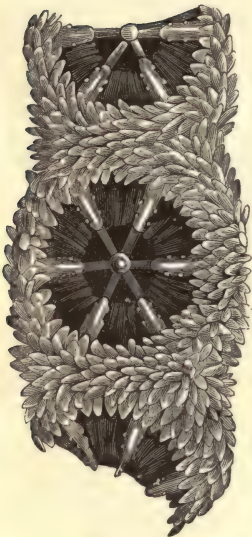


FIG. 33. — Cell of Madrepora Coral, magnified. The cuplike depression at the top of a coral skeleton is called calice.



FIG. 34. — Fragment of Red Coral (*Coralium rubrum*), showing living cortex and expanded polyps. Mediterranean.

Australia is 1250 miles in length. All reefs begin as fringing reefs, and are gradually changed into the other

forms by the slow sinking of the bottom of the ocean, or by the death, decay, and disintegration of the corals on the landward side of the reef, where the food supply is necessarily restricted.

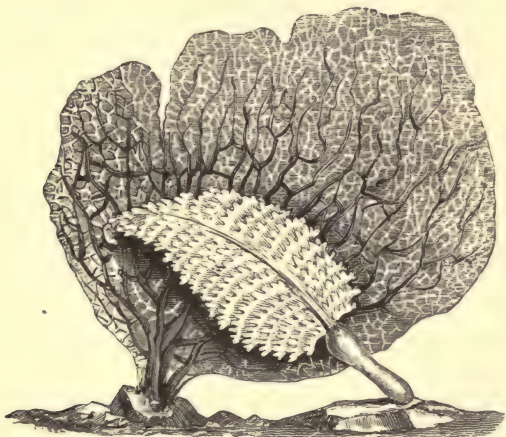


FIG. 35. — Sea Fan (*Gorgonia*) and Sea Pen (*Pennatula*).

(2) **Sclerobasic Corals.** — *Corallium rubrum*, the precious coral of commerce, is shrublike, about a foot high, solid throughout, taking a high polish, finely grooved on the surface, and of a crimson or rose-red color. In the living state the branches are covered with a red cœnosarc studded with white polyps (Fig. 34).

CLASS 4. — Ctenophora

The *Ctenophora* (as the *Pleurobrachia*, *Cestum*, and *Beroë*) are transparent and gelatinous, swimming on the ocean by means of eight comblike, ciliated bands,



FIG. 36. — A Ctenophore (*Pleurobrachia pileus*); natural size.

which work like paddles. The body is not contractile, as in the jellyfishes. They are considered the highest of cœlenterates, having a complex nutritive apparatus and a definite nervous system. There is no trace of a polyp stage in their development, and they do not form colonies. They are found in all regions of the ocean, from the arctics to the tropics.

Branch IV. — PLATYHELMINTHES

The group formerly called *Vermes* or worms was composed of animals so very different in form and structure that it has now been subdivided into several branches, viz.: *Platyhelminthes*, or flat worms; *Nemathelminthes*, or round worms; *Trochelminthes*, or rotifers; *Molluscoïda*, including the Polyzoa and Brachiopoda; and *Annulata*, or segmented worms. All these forms agree in being distinctly bilaterally symmetrical animals, as contrasted with the apparently radial arrangement of parts seen in the *Cœlenterata* and *Echinodermata*, and in having the three body layers — ectoderm, mesoderm, and endoderm — well developed, the mesoderm or middle layer being relatively of more importance than in any preceding group.

The Platyhelminthes, or flat worms, include some free forms, as *Planaria*, which is common in fresh water, and the tapeworms and flukes among the parasites. As a group, they are soft-bodied, flattened animals, without skeletal parts of any kind. There is no distinct body cavity nor blood-vascular system nor anal opening. The digestive system may be entirely absent, as in the tapeworm, or it may be much branched and highly complicated in structure, as in the planarians.

The tapeworm (*Tænia*) consists of the so-called head and the body segments, which are really reproductive

joints. It develops from the egg in the digestive canal of the pig, burrows into the muscular tissue of the animal, and there becomes encased. Pork containing

these cysts is called "measly pork." If the pork be eaten by man, in an uncooked condition, this case is dissolved by the gastric juice, and the embryo thus released attaches itself to the intes-

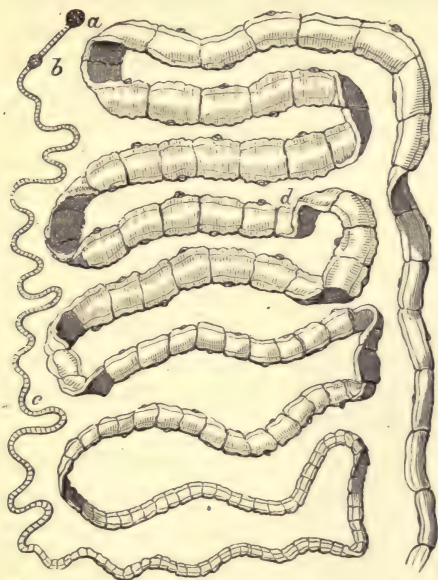


FIG. 37. — Tapeworm (*Tania solium*): a, head; b, c, d, segments of the body.



FIG. 38. — Planarian Worm.

tine by its "head," and develops into the tapeworm by budding off the reproductive segments, or proglottides. As these become ripe and filled with fertilized eggs, they are detached, and pass off with the excrement.

The disease called "rot," in sheep, is produced by the fluke (*Distoma*), which grows in the bile ducts of the sheep.

The flat worms are the most widely distributed of all animals above the Protozoa. They are found on land, at various depths in bodies of fresh water, and in the sea. They also occur as parasites in animals in almost every class of the Metazoa.

Branch V. — NEMATHELMINTHES

The round, or thread, worms include free forms, as the vinegar eel; parasitic forms, as the pin worm (*Ascaris*) and trichina; and forms free when adult, and parasitic when young, as the hair worm (*Gordius*). The body is usually elongated and cylindrical in shape, whence the name. In most forms there are plainly marked digestive and nervous systems.

The trichina is usually derived by man from

the flesh of the pig. It exists in the muscles, inclosed in microscopic cases or cysts, composed of calcareous matter. If the meat be eaten uncooked or partially cooked, the cases are dissolved, and the trichinæ become sexually mature in the intestines. The young are produced and burrow their way into the

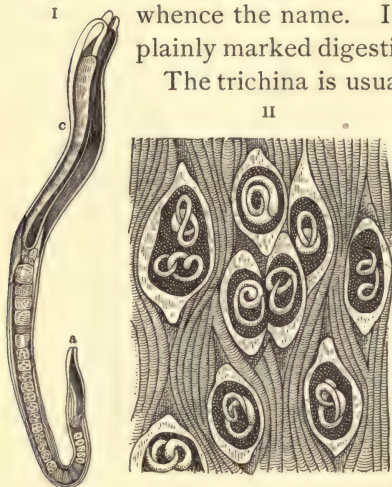


FIG. 39. — *Trichina spiralis* (much enlarged): I, male; a, mouth; c, intestine; II, capsules, with trichinæ in muscle.

muscles, usually of the back and limbs, where they become encysted in the muscle fibers. In burrowing they cause great pain and fever, and sometimes death. The adult trichina is about $\frac{1}{12}$ of an inch long.

The "horse-hair snake," a hair worm (*Gordius*), passes the early part of its existence in larval or adult insects, e.g., the cricket. When mature the worms leave the body of the insect and lay their eggs in damp places. The eggs or the immature worms are then taken into the bodies of other insects in which the parasites later reach their full development.

Branch VI. — TROCHELMINTHES

The wheel animalcules, or rotifers, mostly found in fresh water, are composed of a few ill-defined segments, and have on the anterior end a disk which is ciliated on the edge, the motion of the cilia causing the appearance of a rotating wheel, whence the name. They are from $\frac{1}{200}$ to $\frac{1}{36}$ of an inch long. They have a well-developed digestive system, the food consisting of minute organisms, and a rudimentary nervous system. Rotifers have been kept for several years in a dried condition and have afterward been revived (Fig. 40).

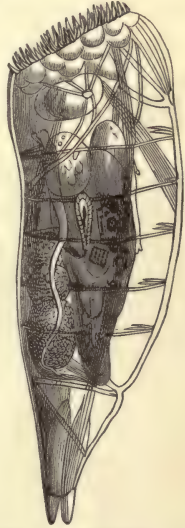


FIG. 40. — Rotifer, or "Wheel animalcule" (*Hydatina*), highly magnified.

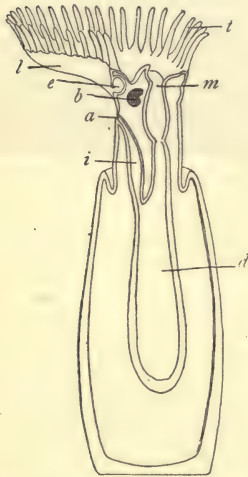


FIG. 41. — Diagram of a Polyzoan: *l*, lophophore bearing tentacles, *t*; *m*, mouth; *d*, digestive cavity; *i*, intestine; *a*, anus; *e*, excretory organ; *b*, "brain." Much magnified.

Branch VII. MOLLUSCOIDA

These animals have generally a body cavity, in which lies the alimentary canal, bent in such a manner that the mouth and the anal opening are close together. Near the mouth is a curved ridge, the *lophophore*, bearing tentacles. There is a very rudimentary nervous system (Fig. 41).

The Polyzoa resemble polyps in appearance, living in clusters, each individual inhabiting a delicate cell, or tube, and having a

simple mouth surrounded with ciliated tentacles. The colony often takes a plantlike form; sometimes spreads, like fairy chains or lacework, over other bodies; or covers rocks and seaweeds in patches with a delicate film. The majority secrete carbonate of lime. A polyzoan shows its superiority to the coral, which it resembles, in possessing a distinct alimentary canal and a nervous system. The cells of a group are never con-



FIG. 42. — Polyzoans: 1. *Hornera lichenoides*, natural size. 2. Branch of the same; magnified. 3. *Discopora Skenel*, greatly enlarged.

nected by a common tube, as in coelenterates. There are both marine and fresh-water species.

The Brachiopoda or “lamp shells” have a bivalve shell, the valves being applied to the dorsal and ventral sides of the body. The valves are unequal, the ventral being usually larger, and more convex; but they are symmetrical, *i.e.*, a vertical line let fall from the hinge divides the shell into two equal parts. The ventral valve has, in the great majority, a prominent beak, perforated by a *foramen*, or hole, through which a fleshy stalk protrudes to attach the animal to submarine rocks.

The valves are opened and shut by means of muscles, and in most cases they are hinged, having teeth and sockets near the beak. The mouth faces the middle of the margin opposite the beak; and on either side of it is a long fringed "arm," generally coiled up, and supported by a calcareous framework. The animal,



FIG. 43. — A Brachiopod (*Terebratulina septentrionalis*). Atlantic coast.

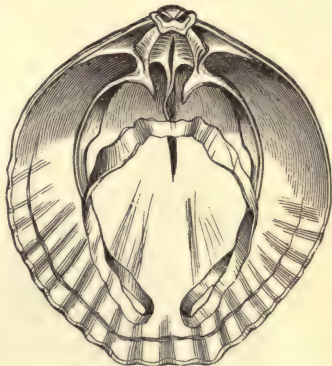


FIG. 44. — Dorsal Valve of a Brachiopod (*Terebratula*), showing, in descending order, cardinal process, dental sockets, hinge plate, septum, and loop supporting the ciliated arms.

having no gills, respire by the arms and the mantle. Brachiopods were once very abundant, over two thousand extinct species having been described; but only about a hundred species are now living.¹³ These are all marine, and fixed. The animals in this group are related to the mollusca.

Branch VIII. — ECHINODERMATA

The echinoderms, as starfishes and sea urchins, are characterized by the possession of a distinct nervous system (a ring around the mouth with radiating branches); an alimentary canal, completely shut off from the body cavity, having both oral and anal apertures; a water-vascular system of circular and radiating canals, connected with the outside water by means of the madreporic tubercle, and a symmetrical arrangement of all the

parts of the body around a central axis in multiples of five,¹⁴ this radial arrangement, however, concealing a definite bilateral symmetry. They are, thus, much more highly organized than the coelenterates, with which group they have very little in common except



FIG. 45.—Forms of Echinoderms, from radiate to annulose type: *a*, Crinoids; *b*, Ophiurans; *c*, Starfish; *d*, Echini; *e*, Holothurians.

their apparent radial symmetry. In the course of development in echinoderms metamorphosis occurs, the larval forms bearing no resemblance to the adults.

There are five principal classes, all exclusively marine and solitary, and all having the power of secreting more or less calcareous matter to form the skeleton.

CLASS I. — **Asteroidea**

Ordinary starfishes consist of a flat central disk, with five or more arms, or lobes, radiating from it, and containing branches of the viscera. The skeleton is leathery, hardened by small calcareous plates (twelve thousand by calculation), but somewhat flexible. The mouth is below; and the rays are furrowed underneath, and pierced with

numerous holes, through which pass the suckerlike tentacles—the organs of locomotion and prehension. The red spots at the ends of the rays are eyes. The usual color of starfishes is yellow, orange, or red. They abound on every shore, and are often seen at low tide half

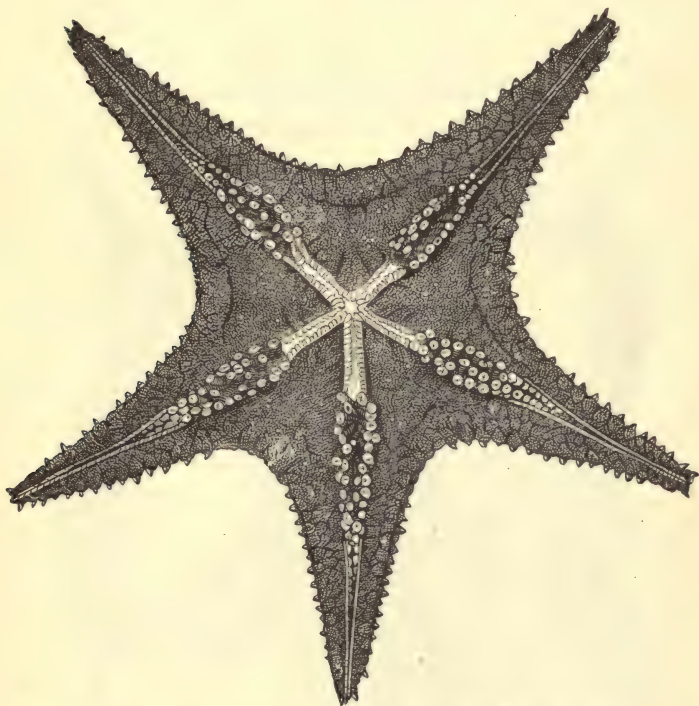


FIG. 46.— Under surface of Starfish (*Goniaster reticulatus*), showing ambulacral grooves and protruded suckers.

buried in the sand, or slowly gliding over the rocks. Cold fresh water quickly kills them. They have to a high degree the power of casting off their rays and of reproducing the lost parts. They are carnivorous, very voracious, and are the worst enemies of the oyster.

About two hundred and fifty species are known. The common starfish (*Asterias*) has four rows of feet in each ray. *Solaster*, the "sun star," has numerous rays with two rows of feet in each. *Goniaster* is somewhat pentagonal in form with feet arranged as in the "sun star." Asteroidea are found as fossils.

CLASS 2. — Ophiuroidea

These are star-shaped echinoderms with a central disk and five flexible, jointed arms distinctly marked off

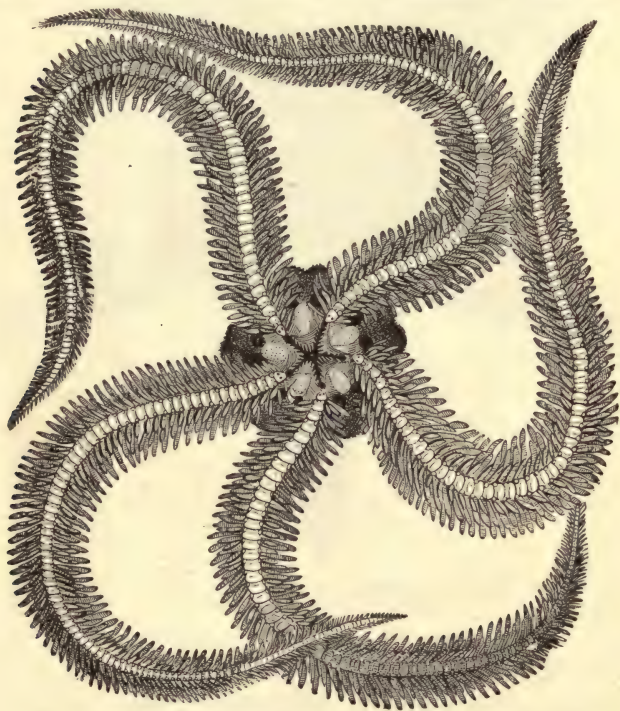


FIG. 47. — *Ophiocoma russei*, an Ophiuran; natural size. West Indies.

from the disk, the latter containing all the visceral parts. There is no anal opening and the madreporite is on the

same side as the mouth. Ambulacral grooves are lacking and the tube feet are rudimentary, locomotion being effected by movements of the very flexible and muscular arms.

The brittle star (*Ophiura*) is common along the Atlantic coast. *Astrophyton*, the "basket fish," has rays which are very much branched.

CLASS 3.—Echinoidea

These are free echinoderms with a globular or disk-shaped shell composed of closely-joined calcareous plates. There are no ambulacral grooves, the tube feet projecting through openings in the plates arranged either along meridional lines or in the form of a star-shaped rosette.

The sea urchin is encased in a thin, hollow, spherical shell covered with spines.¹⁵ The mouth is underneath,

and contains a dental apparatus more complicated than that of any other creature. It leads to a digestive tube, which extends spirally to the summit of the body. The spines are for burrowing and locomotion, and are moved by small muscles, each being articulated by

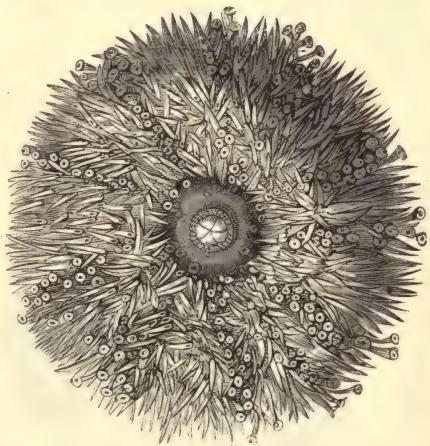


FIG. 48. — Under surface of a Sea Urchin (*Echinus esculentus*), showing the mouth, tips of the teeth, and rows of suckers among the spines. British seas.

ball-and-socket joint to a distinct tubercle. When stripped of its spines, the shell (or "test") is seen to be formed of a multitude of pentagonal plates, fitted together like a

mosaic.¹⁶ Five double rows of plates, passing from pole to pole, like the ribs of a melon, alternate with five other double rows. In one set, called the *ambulacra*, the plates are perforated for the protrusion of tubular feet, or suckers, as in the starfish. So that altogether there are twenty series of plates—ten ambulacral, and ten interambulacral. The shell is not cast, but grows by the enlargement of each individual plate, and the addition of new ones around the mouth and the opposite pole. Echini live near the shore, in rocky holes or under seaweed. They are less active than the starfishes; and feed almost entirely upon seaweed. They reproduce by eggs.

Regular Echini, as the common *Arbacia* or purple sea urchin, and the green sea urchin, are nearly globular, and the oral and anal openings are opposite. *Irregular* Echini, as the *Clypeaster*, are flat, and the anal orifice is near the margin, as in the “sand dollar” or “cake urchin” (*Echinarachnius*).

CLASS 4. — **Holothuroidea**

These wormlike “sea slugs,” as they are called, have a soft, elongated body, with a tough, contractile skin



FIG. 49. — Sea Slugs (*Holothuria*).

containing small calcareous plates. One end is abruptly terminated, and has a simple aperture for a mouth, en-

circled with feathery tentacles. There are usually five longitudinal rows of ambulacral suckers, but only three are used for locomotion, of which one is more developed than the rest. The mouth opens into a pharynx leading to a long intestinal canal extending through the body. Holothurians have the singular power of ejecting most of their internal organs, surviving for some time the loss of these essential parts, and afterward reproducing them. They occur on nearly every coast, especially in tropical waters, where they sometimes attain the length of three or four feet. As found on the beach after a storm, or when the tide is out, they are leathery lumps, of a reddish, brownish, or yellowish color. They may be likened to a sea urchin devoid of a shell, and long drawn out, with the axis horizontal, instead of vertical. They feed on small animals which they catch with their tentacles, and upon organic particles from the sand.

CLASS 5. — Crinoidea

The crinoids, or "sea lilies," are fixed to the sea bottom, temporarily or permanently, by means of a hollow, jointed, flexible stem. On the top of the stem is the body proper, resembling a bud or expanded flower, containing the digestive apparatus, and bearing the branched arms. The mouth looks upward. There is a complete skeleton for strength and support, the entire animal — body, arms, and stem — consisting of thousands of pieces embedded in the tissue of the body. Crinoids were very abundant in the old geologic seas, and many limestone strata were formed out of their remains. They are now nearly extinct: dredging in the deep parts of the oceans has brought to light a few living representatives. *Pentacrinus* is permanently attached, but the rosy, or feather star, is free during its adult life.



FIG. 50. — A living Crinoid (*Pentacrinus asteria*) one fourth natural size.
West Indian Seas.

Branch IX. — ANNULATA

The Annelides include the highest and most specialized Worms. They have many segments, spines, or suckers for locomotion, a supra-esophageal brain, a ventral chain of ganglia, and usually a closed blood system.

There are two principal classes : *Chætopoda*, or bristle-footed worms ; and *Hirudinea*, or leeches. The former

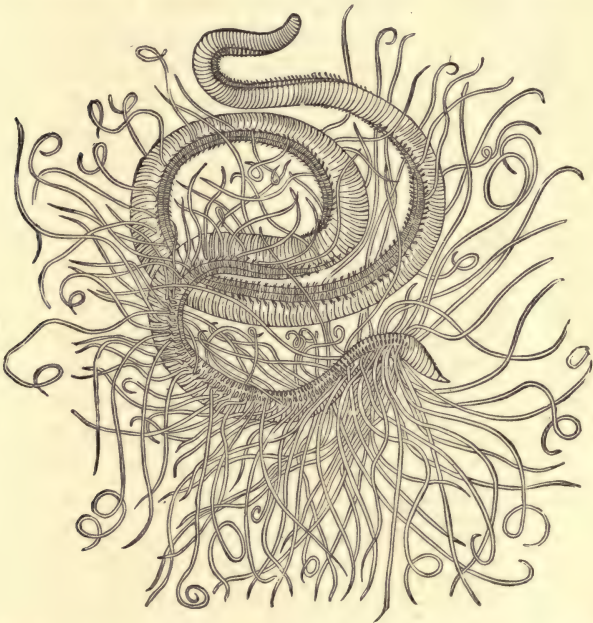


FIG. 51. — Marine Worm (*Cirratulus grandis*), with extended cirri. Atlantic.

class includes the earthworms (*Lumbricus* and *Allolobophora*), the sandworm (*Nereis*), and the lobworm (*Arenicola*).

The earthworm develops from eggs laid, several in a capsule, in the earth or near refuse heaps, under boards

and straw. Its cylindrical body consists of numerous segments, the wall being very muscular and covered by a tough, smooth, transparent cuticle. The body cavity is subdivided by numerous transverse membranous partitions. The digestive system extends throughout the body and there are well-developed nervous and circulatory systems. The former lies

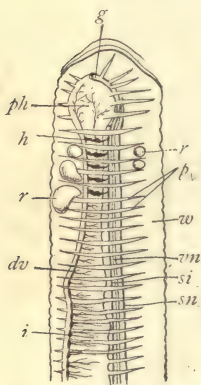


FIG. 52. — Earthworm, internal anatomy of the anterior region. The body has been opened along the dorsal line and the internal organs turned to the left; *ph*, pharynx; *h*, "heart"; *p*, muscular partitions; *w*, wall of body; *r*, reproductive organs (in part); *dv*, dorsal blood vessel; *i*, intestine; *g*, "brain"; *vn*, ventral nerve cord; *si*, subintestinal blood vessel; *sn*, subneural blood vessel.

mainly below the digestive organs and consists of a nerve cord running the length of the body. This cord is composed of pairs of ganglia connected by longitudinal and transverse branches. Above the mouth opening is a pair of ganglia forming the "brain." The larger blood vessels surround the esophagus and one, the dorsal vein, lies above the digestive system and may be seen through the skin on the back. There are no well-defined sense organs, although, judging from experiments, the earthworm is sensitive to touch, is affected by changes in the intensity of light, and gives evidence of having the sense of taste. Respiration is carried on by the vascular skin, there being no lungs or gills. Earthworms feed

upon decaying vegetable matter and upon organic particles contained in the earth, swallowed in the process of making the burrow, or for the sake of the contained food. The refuse from the body is piled up around the mouth of the burrow in the form of pellets. The amount of earth annually brought up from the deeper layers of the soil is sufficient to be of considerable geological and economic importance.

The earthworm belongs to the subclass *Oligochæta*, the members of which have but few bristles on each segment.

Nereis lives in the sea, under rocks and among seaweeds. Like the earthworm, it has a distinctly segmented body. There is a well defined head, bearing sense organs, as eyes and tentacles. The throat is provided with two protrusible jaws, by means of which the worm seizes its food, often living prey (Fig. 215). Each segment bears a pair of flattened, paddlelike *parapodia*, which enable the worm to swim rapidly. The arrangement of the digestive, nervous, and circulatory systems is much like that seen in the earthworm.

Nereis is a member of the subclass *Polychæta*, which is characterized by the presence of numerous bristles on each segment.

The leeches are externally segmented, usually flattened, and have a sucking disk at each end of the body. The mouth is in the anterior disk and is provided with three semi-circular, saw-toothed jaws, by means of which the leech makes the incision through which it sucks the blood of its prey. The disks are also used for locomotion. The digestive system is very capacious, and some leeches can live even if not fed more often than once in two or three months. Leeches are generally freshwater animals, though some kinds are found in the sea and others live on land.

Branch X. — ARTHROPODA

This is larger than all the other branches put together, as it includes the animals with jointed legs, such as crabs and insects. These differ widely from the moluscan type in having numerous segments, and in showing a repetition of similar parts; and from the worms

in having jointed appendages and a definite number of segments.

The skeleton is outside, and consists of articulated segments or rings. The limbs, when present, are likewise jointed and hollow. The jaws move from side to side. The nervous system consists mainly of a double chain of ganglia, running along the ventral surface of



FIG. 53. — Diagram of the structure of an Arthropod (after Schmeil): *a*, antenna; *c*, circulatory system; *d*, alimentary canal; *n*, nerve cord; *g*, ganglion; *s*, skeleton.

the body under the alimentary canal. The brain is connected to the ventral ganglia by a ring encircling the gullet. The alimentary

canal and the circulatory apparatus are nearly straight tubes lying lengthwise—the one through the center, and the other along the back. The skeleton is composed of a horny substance (chitin), or of this substance with carbonate of lime. All the muscles are nearly always striated.

There are five classes, of which the first almost exclusively is water breathing, having gills, and the others principally air breathing, being provided with tracheæ.

CLASS I. — Crustacea

The Crustacea, with few exceptions, are water breathing Arthropoda, usually with two pairs of antennæ.¹⁷ Among them are the largest, strongest, and most voracious of the branch, armed with powerful claws and a hard cuirass, bristling with spines. Although constructed on a common type, crustaceans exhibit a wonderful diversity of external form: contrast, for example, a barnacle and a crab. We will select the lobster as illustrative of the entire group.

A typical crustacean consists of twenty segments, of which five belong to the head, eight to the thorax, and seven to the abdomen.¹⁸ In the lobster, however, as in all the higher forms, the joints of the head and thorax are welded together into a single piece, called the *cephalothorax*. On the front of this shield is a pointed process or *rostrum*; and attached to the last joint of the abdomen (the so-called "tail") is the sole representative of a tail — the *telson*. The skeleton is a mixture of chitin and calcareous matter.¹⁹

On the under side of the body we find numerous appendages, feelers, jaws, claws, and legs beneath the cephalothorax, and flat swimmerets under the abdomen. In fact, every segment except the last, carries a pair of movable appendages, consisting typically of a stalk or *protopodite*, bearing two branches, the *exopodite* and the *endopodite*.

The five segments of the head are compressed into a very small space, yet have the following members:²⁰ the short and the long antennæ; the mandibles, or jaws, between which the mouth opens; and the

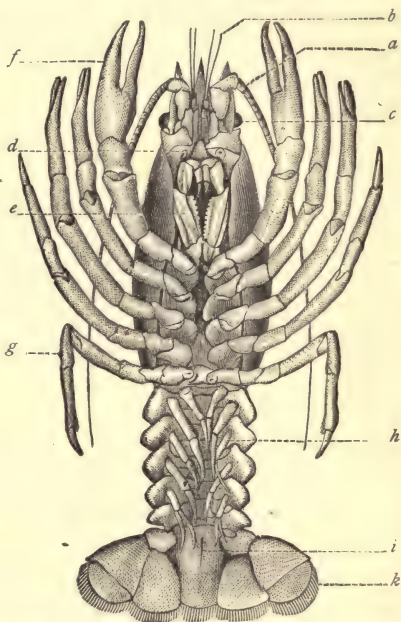


FIG. 54. — Under side of the Crayfish, or Fresh-water Lobster (*Astacus fluviatilis*): *a*, first pair of antennæ; *b*, second pair; *c*, eyes; *d*, opening of kidney; *e*, foot jaws; *f*, *g*, first and fifth pair of thoracic legs; *h*, swimmerets; *i*, anus; *k*, caudal fin.

two pairs of maxillæ. The thorax carries three pairs of modified limbs, called "foot jaws," and five pairs of legs. The foremost legs, "the great claws," are extraordinarily developed, and terminated by strong pincers (*chelæ*). Of the four slender pairs succeeding, two are furnished with claws, and two are pointed. The last pair of swimmerets, together with the telson, form the caudal fin — the main instrument of locomotion; the others (called "swimmerets") are used by the female for carrying her eggs. The eyes are raised on stalks, so as to be movable (since the head is fixed to the thorax), and are compound, made up of about two

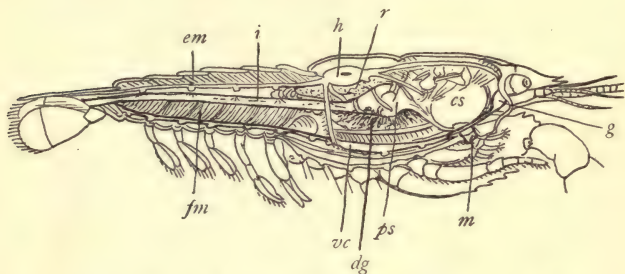


FIG. 55. — Internal anatomy of the Crayfish: *em*, extensor muscle of abdomen; *fm*, flexor muscle of abdomen; *m*, mouth; *cs*, cardiac portion of stomach; *ps*, pyloric portion of stomach; *dg*, digestive gland; *h*, heart; *r*, reproductive gland; *i*, intestine; *g*, "brain"; *vc*, ventral nerve cord.

thousand five hundred square facets. On the base of each small antenna is a minute sac, whose mouth is guarded by hairs: this is the organ of hearing. The gills, twenty on a side, are situated at the bases of the legs and inclosed in two chambers, into which water is freely admitted, in fact, drawn, by means of a curious attachment to one of the maxillæ, which works like a paddle or scoop. The heart is a single oval cavity, and drives arterial blood — a milky fluid full of corpuscles. The alimentary canal consists of a short gullet,

a gizzardlike stomach containing teeth, and a straight intestine.

Crustaceans pass through a series of strange metamorphoses before reaching their adult form. They also periodically cast the shell, or molt, every part of the integument together with the lining of the gullet and stomach being renewed ; and another remarkable endowment is the spontaneous rejection of limbs and their complete restoration. Many species are found in fresh water, but the class is essentially marine and carnivorous.

Of the numerous orders of this great class we will mention only the following :—

1. *Phyllopoda* ; small, almost microscopic, aquatic crustacea, with the appendages showing very little differentiation, no gastric teeth, the



FIG. 56. — Water Fleas: *a*, *Cyclops* (after Vosseler); *b*, *Daphnia* (after Vosseler); *c*, *Cypris* (after Baird).

body distinctly segmented and covered by a cephalic shield. The appendages posterior to the head are leaflike, hence the name of the order. Included here are the brine shrimp (*Artemia*), and the fresh-water forms *Branchipus* and *Daph-*

nia, the bivalve shell of the latter giving it the appearance of a mollusk (Fig. 56).

2. *Ostracoda* ; minute crustacea with an unsegmented body inclosed in a bivalve carapace or shell. This order is represented in fresh water by *Cypris* (Fig. 56).

3. *Copepoda* ; mostly of small size, with an elongated and, usually, a distinctly segmented body without dorsal shell. In this order belong the fish lice, and the water flea (*Cyclops*) of fresh water, the female of which is often seen darting about in aquarium jars bearing its two egg masses attached to the abdomen (Fig. 56).

4. *Cirripedia* ; marine crustacea, imperfectly seg-

mented, and fixed or parasitic in adult life, growing head downward in their shell. The feathery, branched,

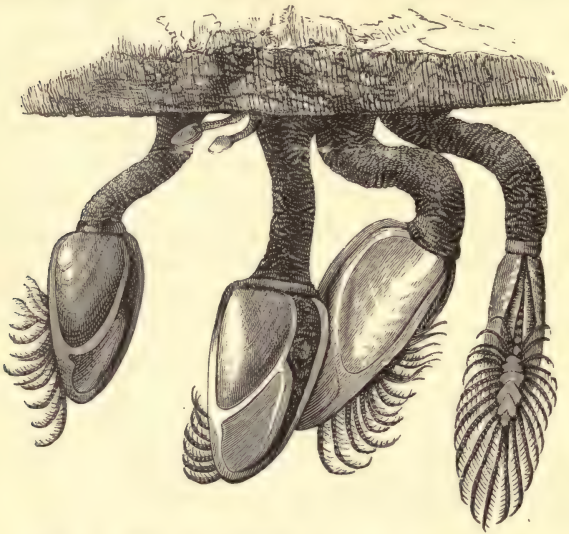


FIG. 57. — Barnacles, or Pedunculate Cirripedes (*Lepas anatifera*).

thoracic feet are protruded through the opening of the shell to grasp particles of food. *Lepas*, the ship barnacle, grows attached to floating timber and the bottoms of ships by a long, leathery stalk (Fig. 57). The acorn shells (*Balanus*) grow on rocks between tide marks, their white, conical “shells” forming an incrusting layer on the rock (Fig. 58).

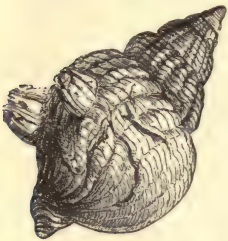


FIG. 58. — Acorn Shells (*Balanus*) on the shell of a whelk (*Buccinum*).

5. *Decapoda*; large, highly organized crustaceans, having usually a thorax of eight and an abdomen of seven segments, the anterior regions of the carapace united to form a cephalothorax; the eyes are borne on stalks and the gills are thoracic.

There are ten legs. Here belong the lobster (*Homarus*) (Fig. 59), and crayfishes (*Astacus* and *Cambarus*) (Fig.



FIG. 59. — Lobster (*Homarus vulgaris*).



FIG. 60. — Swimming Crab (*Platyonychus*).

54), prawn (*Palæmon*), shrimp (*Crangon*), hermit crab (*Pagurus*), and crab (*Platyonychus*) (Fig. 60).

Crabs differ from lobsters chiefly in being formed for creeping at the bottom of the sea instead of swimming, and in the reduction of the abdomen or "tail" to a rudiment, which folds into a groove under the enormous thorax. They are the highest and largest of living Crustacea: they have been found at Japan measuring twenty feet between the tips of the claws.

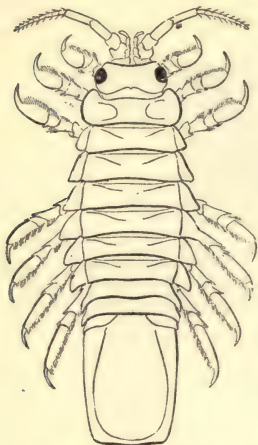


FIG. 61. — *Idotea robusta*.
U. S. coast.

6. *Arthrostraca*; with the thorax reduced to six or seven segments owing to the fusion of one or two of the anterior thoracic segments with the head; eyes usually sessile. This order includes the wood louse or sow bug (*Oniscus*) found in damp places, the slaters (*Idotea*) (Fig. 61), and the sand fleas (*Gammarus*).



FIG. 62. — *Amphithoë maculata*: a sand flea.

CLASS 2. — Onycophora

This class includes only a single genus, *Peripatus*, the species of which are all terrestrial, living in damp places, and are confined mainly to the Southern Hemisphere. *Peripatus* is a cylindrical, soft-bodied animal resembling a caterpillar, though the body is not segmented. There is a plainly marked head bearing a pair each of eyes, antennæ, and jaws. The body is

supported on many pairs (fourteen to forty-two, according to the species) of short, fleshy appendages which are not jointed. These animals are chiefly of interest because of the fact that in certain features of structure, as the size of the brain, the presence of tracheæ, the



FIG. 63. — *Peripatus* ; natural size.

arrangement of the circulatory system, and the clawed appendages, and in their mode of development, they resemble the Arthropods, while in other respects, especially as regards the excretory and nervous systems they approach the Annulata and the Flatworms. Thus, the class serves to connect the Arthropods and the "Worms."

CLASS 3. — Myriapoda

Myriapods are air-breathing Arthropods having the body divided into similar segments, so that thorax and abdomen are scarcely distinguishable. They resemble worms in form and in the simplicity of their nervous and circulatory systems ; but the skin is stiffened with chitin, and the legs (indefinite in number) are articulated. The legs resemble those of insects, and the head appendages follow each other in the same order as in insects — eyes, antennæ, mandibles, maxillæ, and labium. They breathe by tracheæ, and have two antennæ and a pair of eyes.

There are two important orders : —

1. *Chilopoda*, characterized by having a flattened body composed of about twenty segments, each carrying one pair of legs, of which the hindermost is converted into

spines. They have longer antennæ than the preceding, and the mouth is armed with two formidable fangs connected with poison glands. They are carnivorous and active. Such is the Centipede (*Scolopendra*, Fig. 80).

2. *Diplopoda*, having a cylindrical body, each segment, except the anterior, being furnished with two pairs of legs. They are slow of locomotion, harmless, and vegetarian. The thousand-legged worm (*Julus*) is a common representative.

CLASS 4.—Insecta

Insects are distinguished by having head, thorax, and abdomen distinct, three pairs of jointed legs, one pair of antennæ, and generally two pairs of wings. The number of segments in the body never exceeds twenty. The head, apparently one, is formed by the union of four segments. The thorax consists of three, —the *prothorax*, *mesothorax*, and *metathorax*, — each bearing a pair of legs; the wings, if present, are carried by the last two segments (Fig. 295). The abdomen is usually composed of ten segments, more or less movable upon one another. The skin is hardened with chitin, and to it, as in all Arthropods, the muscles are attached. All the appendages are hollow.

The antennæ are inserted between or in front of the eyes. There is a great variety of forms, but all are tubular and jointed. They are supposed to be organs of touch, and seem also to be sensitive to sound and odor (Fig. 344). The eyes are usually compound, composed of a large number of hexagonal corneæ, or facets (from fifty in the ant to many thousands in the winged insects) (Fig. 352). They are never placed on movable stalks, as the lobster's. Besides these, there are three simple eyes, called *ocelli*. The mouth may be fitted for biting (*masticatory*), as in beetles, or for sucking (*suctorial*), as in

butterflies. The masticatory type, which is the more complete, and of which the other is but a modification, consists of four horny jaws (*mandibles* and *maxillæ*) and an upper and an under lip (*labrum* and *labium*). Sensitive palpi (*maxillary* and *labial*) are developed from the lower jaw and lower lip. The labium is also prolonged into a *ligula*, or tongue (Figs. 219, 220, 221).

The legs are invariably six in the adult, the fore legs directed forward and the hinder pairs backward. Each consists of a hip, thigh, shank, and foot.²¹ Some larvæ have also "false legs," without joints, on the abdomen, upon which they chiefly rely in locomotion (Fig. 73). The wings are expansions of the crust, stretched over a network of horny

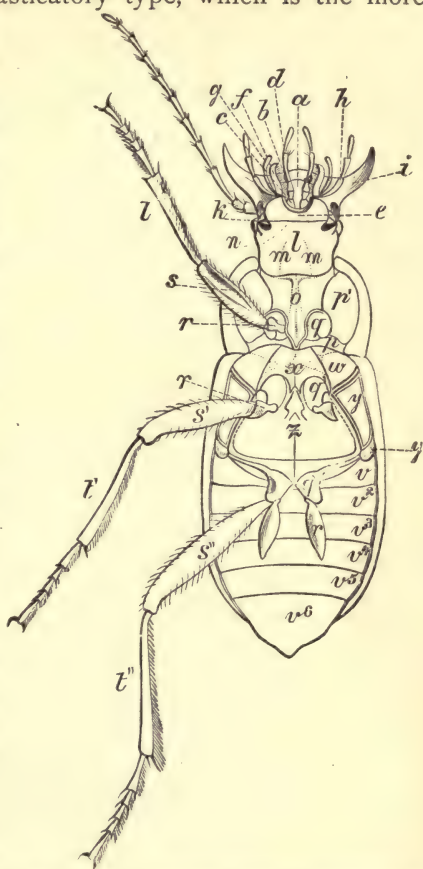


FIG. 64. — Under surface of a Beetle (*Harpalus caliginosus*): *a*, ligula; *b*, paraglossæ; *c*, supports of labial palpi; *d*, labial palpus; *e*, mentum; *f*, inner lobe of maxilla; *g*, outer lobe; *h*, maxillary palpus; *i*, mandible; *k*, buccal opening; *l*, gula, or throat; *m*, buccal sutures; *n*, gular suture; *o*, prosternum; *p*, episternum of prothorax; *p'*, epimeron; *q, q', q''*, coxæ; *r, r, r*, trochanters; *s, s', s''*, femora, or thighs; *t, t', t''*, tibiae; *v*, ventral abdominal segments; *w*, episterna of mesothorax; *x*, mesosternum; *y*, episterna of metathorax; *y'*, epimeron; *z*, metasternum.

tubes (Fig. 278). The venation, or arrangement of these tubes (called *veins* and *veinlets*), particularly in the fore wings, is peculiar in each genus. In many insects, the abdomen of the female ends in a tube which is the sheath of a sting, as in the bee, or of an *ovipositor*, or "borer," as in the ichneumon, by means of which the eggs are deposited in suitable places.

Cephalization is carried to its maximum in this class, and we have animals of the highest instincts under the articulate type. The "brain" is formed of several ganglia massed together, and lies across the upper side of the throat, just above the mouth. The main nerve cord lies along the ventral side of the body, and bears several large ganglia; besides this, there is a visceral nerve representing, in function, the sympathetic system of vertebrates. The digestive apparatus consists of a pharynx, gullet (to which a crop is added in the fly, butterfly, and bee tribes), gizzard, stomach, and intestine (Figs. 239, 240, 241). There are no absorbent vessels, the chyme simply transuding through the walls of the canal. The blood, usually a colorless liquid, is driven by a chain of hearts along the back, *i.e.*, by a pulsating tube divided into valvular sacs, ordinarily eight, which allow the current to flow only toward the head. As it leaves this main pipe, it escapes into the cavities of the body, and thus bathes all the organs. Although the blood does not circulate in a closed system of blood vessels, as in vertebrates, yet it always takes one set of channels in going from the heart, and another in returning. Respiration is carried on by tracheæ, a system of tubes opening at the surface by a row of apertures (*spiracles*), generally nine on each side of the body (Figs. 276, 277, 278).

The sexes are distinct, and the larvæ are hatched from eggs. As a rule, an insect, after reaching the adult, or

imago state, lives from a few hours to several years, and dies after the process of reproduction. Growth takes place only during larval life, and all metamorphoses occur then. Among the social tribes, as bees and ants, the majority (called "workers") do not develop either sex.

Insects (the six-footed arthropods) comprise about one half of the whole animal kingdom as known, more than two hundred and fifty thousand species having been described. They may be grouped into seven principal orders:—

1. *Orthoptera* have four wings: the front pair somewhat thickened, narrow, and overlapping along the back;



FIG. 65. — Metamorphosis of a Cricket (*Gryllus*).

the hind pair broad, net veined, and folding up like a fan upon the abdomen. The hind legs are usually large, and fitted for leaping, all the species being terrestrial, although some fly as well as leap. The eyes are small, the mouth remarkably developed for cutting and grinding. The lar-

væ and pupæ are active and resemble the imago. They are nearly all vegetarian. Each family produces characteristic sounds (stridulation). About ten thousand species have been described. The representative forms are crickets (*Gryllus*), locusts (*Melanoplus*), grasshoppers (*Orchelimum*), walking sticks (*Diapheromera*), and cockroaches (*Periplaneta*).

2. *Neuroptera* have a comparatively long, slender body, and four large, transparent wings, nearly equal in size,



FIG. 66. — Metamorphosis of an Hemipter, Water Boatman (*Notonecta*).

membranous and lacelike. The mouth parts are adapted for biting. Among them are the brilliant dragon flies, or devil's darning needles (*Libellula*), well known by the enormous head and thorax, large, prominent eyes (each furnished with twenty-eight thousand polished lenses), and scorpionlike abdomen; the delicate and short-lived May flies (*Ephemera*); caddis flies (*Phryganea*), whose larvæ live in a tubular case made of minute stones, shells, or bits of wood; the horned corydalis (*Corydalis*), of which the male has formidable mandibles twice as long as the head; and the white ants (*Termes*) of the tropics.



FIG. 67. — Seventeen-year Cicada (*Cicada septendecim*): *a*, pupa; *b*, the same, after the imago, *c*, has escaped through a rent in the back; *d*, holes in a twig, where the eggs, *e*, are inserted.



FIG. 68. — Dragon Fly (*Libellula*).

3. *Hemiptera*, or "bugs," are chiefly characterized by a suctorial mouth, which is produced into a long, hard beak, in which mandibles and maxillæ are modified into bristles and inclosed by the labium. The four wings are irregularly and sparsely veined, sometimes wanting. The body is flat above, and the legs slender. The larva differs from the imago in wanting wings. In some species the fore wings are opaque at the base and transparent at the apex, whence the name of the order. Some feed on the juices of animals, others on plants. Here belong the wingless bed bug (*Cimex*) and louse (*Pediculus*), the squash bug (*Anasa*), water boatman (*Notonecta*), seventeen-year locust (*Cicada*), cochineal (*Coccus*), and plant louse (*Aphis*). More than twenty thousand species are known.

4. *Diptera*, or "flies," are characterized by the rudimentary state of the hinder pair of wings. Although having, therefore, but one available pair, they are gifted with the power of very rapid flight. While a bee moves its wings one hundred and ninety times a second, and a



FIG. 69. — Metamorphosis of the Flesh Fly (*Sarcophaga carnaria*): *a*, eggs; *b*, young maggots just hatched; *c*, *d*, full-grown maggots; *e*, pupa; *f*, imago.

butterfly nine times, the house fly makes three hundred and thirty strokes. A few species are wingless. The eyes are large, with numerous facets. In some forms, as the house fly, all the mouth parts, except the labium, are rudimentary; and the labium has an expanded tip, by means of which the fly licks up its food. In other forms, as the mosquito, the other mouth parts are present as bristles or lancets, fitted for piercing; the thorax is globular, and the legs slender. The larvæ are footless

grubs. The Diptera number about forty thousand. Among them are the mosquitoes (*Culex*); Hessian fly (*Cecidomyia*), so destructive to wheat; daddy longlegs or crane fly (*Tipula*), resembling a gigantic mosquito; the wingless flea (*Pulex*); besides the immense families represented by the house fly (*Musca*) and bot fly (*Æstrus*).

5. *Lepidoptera*, or "butterflies" and "moths," are known chiefly by their four large wings, which are thickly covered on both sides by minute, overlapping scales. The scales are of different colors, and are often arranged in patterns of exquisite beauty. They are in reality modified hairs, and every family has its particular

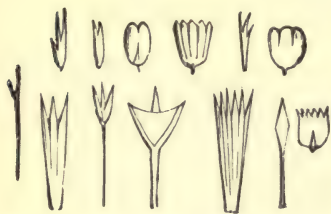


FIG. 70. — Scales from the Wings of various *Lepidoptera*.

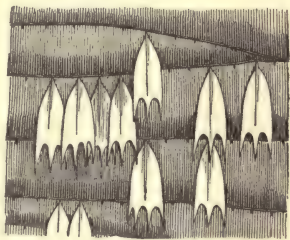


FIG. 71. — Part of the Wing of a Moth (*Samia*), magnified to show the arrangement of scales.

form of scale. The head is small, and the body cylindrical. The legs are of but little use for locomotion. All the mouth parts are nearly obsolete except the maxillæ, which are fashioned into a "proboscis" for pumping up the nectar of flowers. The larvæ, called "caterpillars," have a wormlike form, and from one to five pairs of abdominal legs, or "false legs," in addition to the three on the thorax. The mouth is formed for mastication, and (except in the larvæ of butterflies) the lip has a spinneret connected with silk glands (Fig. 75).

There are two groups: the gay butterflies, having knobbed or hooked antennæ, and flying in the day only, forming one group; and the moths, which generally

prefer the night, and whose antennæ are threadlike and



FIG. 72. — *Vanessa polychloros*, or "Tortoise-shell Butterfly."

often feathery, composing the second group. To this belong the dull-colored *Sphinxes* or "hawk moths,"

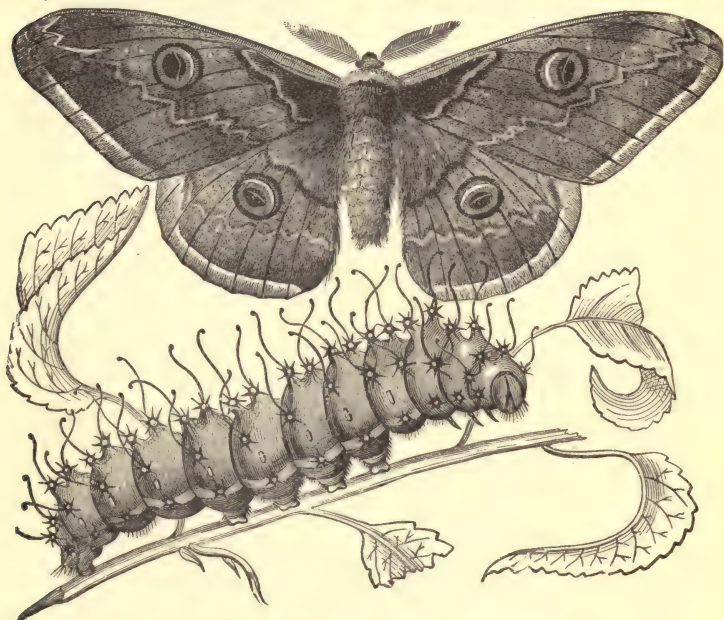


FIG. 73. —Moth and Larva of *Attacus pavonia-major*.

which have antennæ thickened in the middle, and which

fly at twilight. Generally, when at rest, the butterflies keep their wings raised vertically, while the others hold

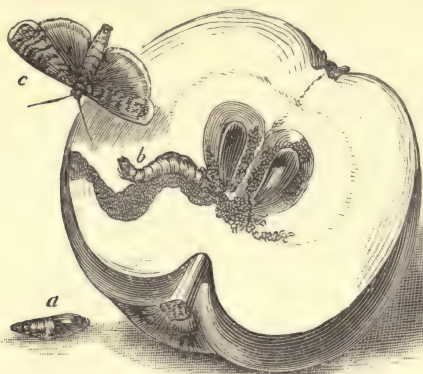


FIG. 74. — Fruit Moth (*Carpocapsa pomonella*): *b*, larva; *a*, chrysalis; *c*, imago.

theirs horizontally. The pupa of the former is unprotected, and is usually suspended by a bit of silk; the pupa of the moths is inclosed in a cocoon.

From twenty-two thousand to twenty-five thousand lepidopterous species have been identified. Some of the most common butterflies are the swallow-tail *Papilio*, the white *Pieris*, the sulphur-yellow *Colias*; the *Argynnis*, with silver spots on the under side of the hind wings; the *Vanessa*, with notched wings. The Sphinges exhibit little variety. They have narrow, powerful wings, and

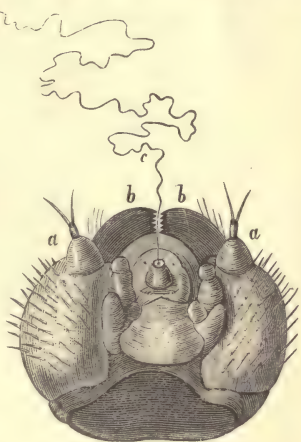


FIG. 75. — Head of a Caterpillar, from beneath: *a*, antennæ; *b*, horny jaws; *c*, thread of silk from the conical fusulus, on either side of which are rudimentary palpi. Magnified.

are sometimes mistaken for humming-birds. The "potato worm" is the caterpillar of a sphinx. The most conspicuous moths are the large and beautiful *Telea*, distinguished by a triangular, transparent spot in the center of the wing; the white *Bombyx*, or "silkworm;" the reddish-brown *Clisiocampa*, whose larva, "the American tent caterpillar," spreads its web in many an apple and cherry tree; the pale, delicate *Geometrids*; and the small but destructive *Tineids*, represented by the clothes moth.

6. *Coleoptera*, or "beetles." This is the largest of the orders, the species numbering about ninety thousand.

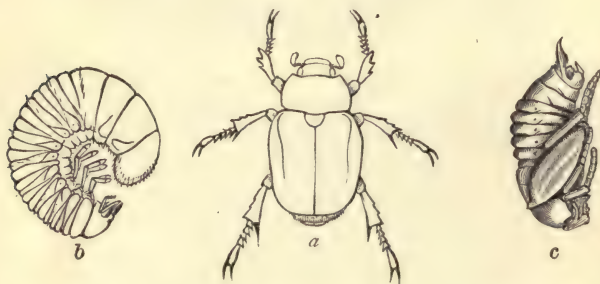


FIG. 76. — *a*, imago, and *b*, larva, of the Goldsmith Beetle (*Cotalpa lanigera*); *c*, pupa of June Bug (*Lachnosterna fusca*).

They are easily recognized by the *elytra*, or thickened, horny fore wings, which are not used for flight, but serve to cover the hind pair. When in repose, these elytra are always united by a straight edge along the whole length. The hind wings, when not in use, are folded transversely. The mandibles are well developed, and the integument generally is hard. The legs are strong, for the beetles are among the most powerful running insects. The larvæ are wormlike, and the pupa is motionless. The highest tribes are carnivorous. The most prominent forms are the savage but beautiful tiger

beetles (*Cicindela*); the common ground beetles (*Harpalus*), whose elytra bear parallel ridges; the diving beetles (*Dytiscus*), with boat-shaped body, and hind legs changed into oars; the carrion beetles (*Silpha*),



FIG. 77. — Sexton Beetles (*Necrophorus vespillo*), with larva and nymph. They are burying a mouse, preparatory to laying their eggs in it.

distinguished by their black, flat bodies and club-shaped antennæ; the goliath beetles (*Goliathus*), the giants of the order; the click beetles (*Alaus*); the lightning bugs (*Pyrophorus*); the spotted lady-birds (*Coccinella*); the showy, long-horned beetles (*Cerambycidæ*); and

the destructive weevils (*Curculionidæ*), with pointed snouts.

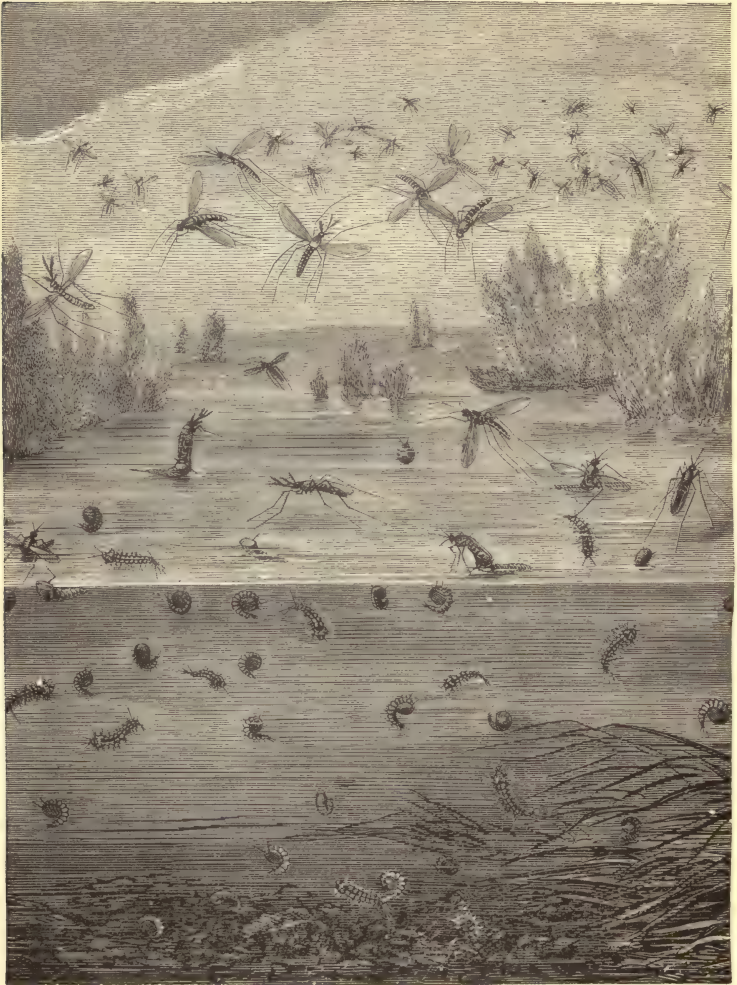


FIG. 78. — Metamorphosis of the Mosquito (*Culex pipiens*).

7. *Hymenoptera*, comprising at least thirty-five thousand species, include the highest, most social, and, we

may add (if we except the silkworm), the most useful, of insects. They have a large head, with compound eyes and three ocelli, mouth fitted both for biting and lapping, legs formed for locomotion as well as support, and four wings equally transparent, and interlocking by small hooks during flight. The females are usually provided with a sting, or borer. The larvæ are footless, helpless grubs, and generally nurtured in cells, or nests. Such are the honey bees (*Apis*), humble bees (*Bombus*), wasps (*Vespa*), ants (*Formica*), ichneumon flies, and gall flies. Those living in societies exhibit three castes: females, or "queens"; males, or "drones"; and neuters, or sexless "workers." There is but one queen in a



FIG. 79. — Honey bee (*Apis mellifica*): *a*, female; *b*, worker; *c*, male.

hive, and she is treated with the greatest distinction, even when dead. She dwells in a large, pear-shaped cell, opening downward. She lays three kinds of eggs: from the first come forth workers, the second produces males, and the last females. The drones, of which there are about eight hundred in an ordinary hive, are marked by their great size, their large eyes meeting on the top of the head, and by being stingless. The workers, which number twenty to one drone, are small and active, and provided with stings, and hollow pits on the thighs, called "baskets," in which they carry pollen. Their honey is nectar elaborated in the crop by an unknown process; while the wax is secreted from the sides of the abdomen and mixed with saliva. There is a subdivision

of extra labor : thus there are wax workers, masons, and nurses. Ants (except the *Saüba*) have but two classes of workers. While ants live in hollow trees or subterranean chambers (called *formicarium*), honey bees and wasps construct hexagonal cells. The comb of the bee is hung vertically, that of the wasp is horizontal.

CLASS 5. — *Arachnida*

The arachnids are closely related to the crustaceans, having the body divided into a cephalothorax and abdomen.²² To the former are attached eight legs of seven joints each ; the latter has no locomotive appendages. The head carries two, six, or eight eyes, smooth and sessile (*i.e.*, not faceted and stalked, as in the lobster), and approaching the eye of the vertebrates in the completeness and perfection of their apparatus. There are no antennæ, the first pair of appendages on the cephalothorax being modified into grasping organs. They are all air breathers, having spiracles which open either into air sacs or tracheæ. The young of the higher forms undergo no metamorphosis after leaving the egg.

Arachnids number nearly five thousand species. The typical forms may be divided into three groups : —

1. *Scorpionida*, or scorpions, characterized by very large maxillary palpi ending in forceps, and a prolonged, jointed post-abdomen. The nervous and circulatory systems are more highly organized than those of spiders ; but the long, tail-like post-abdomen and the abnormal jaws place them in a lower rank. The abdomen consists of twelve segments : the anterior half is as large as the thorax, with no well-marked division between ; the other part is comparatively slender, and ends in a hooked sting, which is perforated by a tube leading to a poison sac. The mandibles are transformed into small, nipping claws, and the eyes generally number six. Respiration is car-

ried on by four pairs of pulmonary sacs which open on the under surface of the abdomen. The heart is a strong artery, extending along the middle of the back, and divided into eight separate chambers. Scorpions are confined to the warm-temperate and tropical regions, usually lurking in dark, damp places.



FIG. 80. — Scorpion (under surface) and Centipede.

2. *Phalangida*, the harvest men, or “granddaddy longlegs” (*Phalangium*), frequently seen about our houses, belong to this order. They have a short, thick, unsegmented body, extremely long legs, and no spinning glands.

3. *Araneida*, or spiders. They are distinguished by their soft, unjointed abdomen, connected to the thorax by a narrow neck, and provided at the posterior end with two or three pairs of appendages, called “spinnerets,” which are homologous with legs. The office of the spinnerets is to reel out the silk from the silk glands,

the tip being perforated by a myriad of little tubes, through which the silk escapes in excessively fine threads. An ordinary thread, just visible to the naked eye, is the union of a thousand or more of these delicate streams of a fluid which, like collodion, hardens on exposure to the air.²³

The mandibles are vertical, and end in a powerful hook, in the end of which opens a duct from a poison

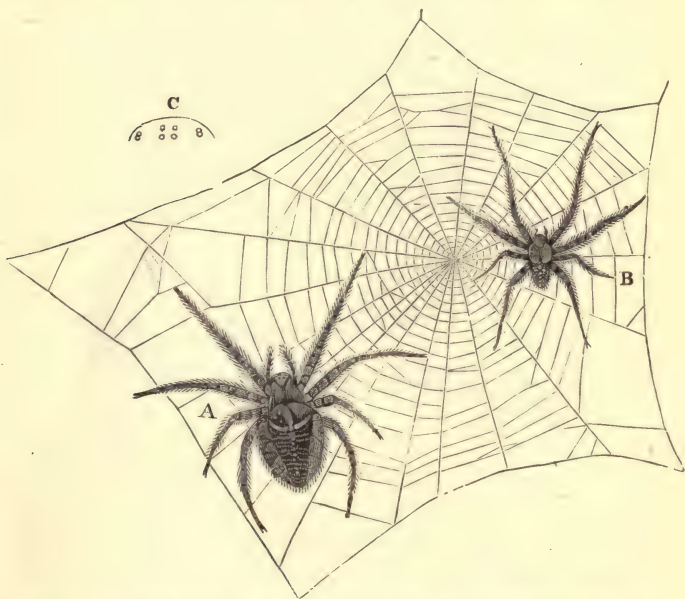


FIG. 81. — A, female Spider; B, male of same species; C, arrangement of the eyes.

gland in the head (Fig. 216). The maxillæ, or “palpi,” which in scorpions are changed to formidable claws, in spiders resemble the thoracic feet, and are often mistaken for a fifth pair. The brain is of larger size, and the whole nervous system more concentrated than in the preceding order. There are generally eight simple eyes, rarely six. They breathe both by tracheæ and

lunglike sacs, from two to four in number, situated under the abdomen. All the species are carnivorous.

The instincts of spiders are of a high order. They are, perhaps, the most wily of arthropods. They display remarkable skill and industry in the construction of their webs; and some species (called "mason spiders") even excavate a subterranean pit, line it with their silken tapestry, and close the entrance with a lid which moves upon a hinge.²⁴

4. *Acarida*, represented by the mites and ticks. They have an oval or rounded body, without any marked articulations, the head, thorax, and abdomen being apparently merged into one. They have no brain; only a single ganglion lodged in the abdomen. They breathe by tracheæ or through the skin. The mouth is formed for suction, and they are generally



FIG. 82. — Spinnerets of the spider, *b, c*; *a*, palpiform organs.



FIG. 83. — A Mite (*Demodex folliculorum*), one of the lowest Arachnids; a parasite in human hair sacs; $\times 125$.

parasitic. The mites (*Sarcoptes*) are among the lowest of articulates. The body is soft and minute. The ticks (*Ixodes*) have a leathery skin, and are sometimes half an inch long. The mouth is furnished with a beak for piercing the animal it infests.

5. *Xiphosura*, Arachnida with a broad carapace covering the cephalothorax, an abdomen consisting of seven firmly united segments ending with a long slender tail of one piece, five pairs of legs on the cephalothorax; the abdomen with five pairs of platelike respiratory organs covered anteriorly by an operculum. The king crab or horseshoe crab (*Limulus*), found on muddy bottoms along the coast, belongs in this order, which is interesting as containing the only living representatives

of the extinct trilobites. *Limulus* was formerly classified among the Crustacea, but is now considered to have its closest affinities among the Arachnida.

Branch XI. — MOLLUSCA

A mollusk is a soft-bodied animal, without internal skeleton, and without segmentation of body or of parts, covered with a moist, sensitive, contractile skin, which, like a mantle, loosely envelops the creature. In some cases the skin is naked, but generally it is protected by a calcareous covering (shell). The length of the body is less in proportion to its bulk than in other animals. The lowest class has no distinct head. The nervous system consists of three well-developed pairs of ganglia, which are principally concentrated around the entrance to the alimentary canal, forming a ring around the throat. The other ganglia are, in most cases, scattered irregularly through the body, and in such the body is unsymmetrical (Figs. 331, 332). The digestive system is greatly developed, especially the "liver," as in many aquatic animals (Figs. 242, 243). Except in the cephalopods, the muscles are attached to the skin, or shell. There is a heart of two chambers (auricle and ventricle) or three (two auricles and ventricle). As in all invertebrates, the heart is arterial. In mollusks, with rare exceptions, we find no repetition of parts along the antero-posterior axis. They are best regarded as "worms" of few segments, which are fused together and much developed. The total number of living species probably exceeds twenty thousand. The great majority are water breathers, and marine; some are fluviatile or lacustrine, and a few are terrestrial air breathers. All bivalves, and nearly all univalves, are aquatic. Each zone of depth in the sea has its particular species. The most important classes are now to be described.

CLASS I. — **Pelecypoda**

These mollusks, formerly called lamellibranchs, are all ordinary bivalves, as the oyster and clam. The shells differ from those of brachiopods in being placed on the right and left sides of the body, so that the hinge is on the back of the animal, and in being unequilateral and equivalved.²⁵ The umbo, or beak, is the point from which the growth of the valve commences. Both brachiopods

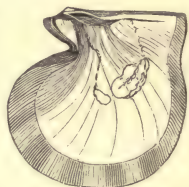


FIG. 84. — Pearl Oyster (*Meleagrina margaritifera*); one fourth natural size. Ceylon.

and pelecypods are headless; but in the latter the mouth points the same way as the umbo, *i.e.*, toward the anterior part. The length of the shell is measured from its anterior to its posterior margin, and its breadth from the dorsal side, where the hinge is, to the opposite, or ventral, edge. The valves are united to the animal by one muscle (as in the oyster), or two (as in the clam), and to each other by a hinge. In some species, as some fresh-water mussels, the hinge is simply an elastic liga-

ment, passing on the outside from one valve to the other just behind the beak, so that it is stretched when the valves are closed. Another is placed between the edges of the valves, so that it is squeezed as they shut, like the spring in a watch case. Such bivalves are said to be edentulous. But in the majority, as the clam and the fresh-water *Unio*, the valves also articulate by interlock-parts called *teeth*. The valves are, therefore, opened by the ligaments, and closed by the muscles.

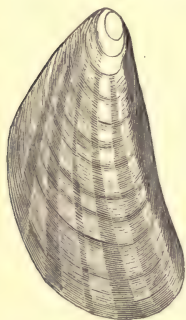


FIG. 85. — Salt - water Mussel (*Mytilus pelucidus*). Atlantic coasts.

The shell is secreted by the mantle.

Lamellibranchs breathe by four hollow, platelike gills (whence the name), two on each side underneath the mantle (Fig. 275), the water being drawn into the cavities in the gills by the action of ciliated cells. In the higher forms, the margin of the mantle is rolled up into two tubes, or siphons, for the inhalation and exhalation of water. They feed on microscopic organisms gathered from the water by the ciliated inner surface of the mantle, the cilia producing a flow of particles toward the mouth.

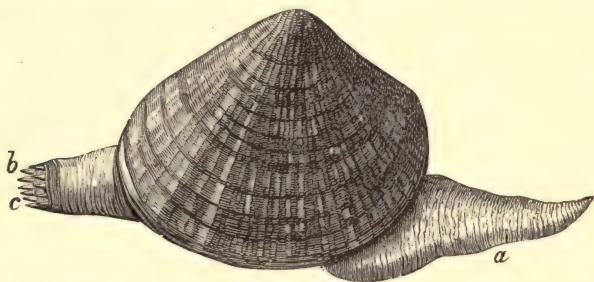


FIG. 86. — Lamellibranch (*Mactra*): *a*, foot; *b*, *c*, siphons.

A few are fixed; the oyster, *e.g.* habitually lying on its left valve, and the salt-water mussel hanging to the rocks by a cord of threads called “*byssus*”; but most have a “foot,” by which they creep about. Unlike the oyster, also, the majority live in an erect position, resting on the edges of their shells. About five thousand living species are known. These are fresh-water and marine, and range from the shore to a depth of a thousand feet.

The chief characters for distinguishing lamellibranchs are the muscular impressions,²⁶ whether one or two; the presence of a pallial sinus, which indicates the possession of siphons; the structure of the gills, and the symmetry of the valves (Fig. 296).

The following are the more important orders, classified according to gill structure:—

1. *Filibranchia*, with two pairs of platelike gills, the filaments being V-shaped, usually two adductor muscles of which the anterior is often the smaller or may even be absent, sea mussel (*Mytilus*) (Fig. 85).

2. *Pseudo-lamellibranchia*, with gills showing vertical folds, a single, large (posterior) adductor muscle, the shell frequently inequivalve, oyster (*Ostrea*) (Fig. 242), scallop (*Pecten*), pearl oyster (*Meleagrina*) (Fig. 84).

3. *Eulamellibranchia*, with gills smooth or vertically plaited and with two adductor muscles of equal size, fresh-water mussel (*Unio* and *Anodonta*), cockle (*Cardium*) (Fig. 87), quahog (*Venus*), shipworm (*Teredo*), and common clam (*Mya*).²⁷

CLASS 2. — Amphineura

The animals in this class were formerly placed among the Gastropoda, but are now considered to be sufficiently distinct to be grouped by themselves. They are bilaterally symmetrical, elongated mollusks, with a shell consisting of eight separate pieces, or else entirely lacking. The mantle is not divided into paired lobes as in the bivalves. *Chiton*, a sluggish animal with the habit of the limpet, is one of the best-known forms (Fig. 100). The shell-less members of the class are the lowest in organization of all of the mollusks.

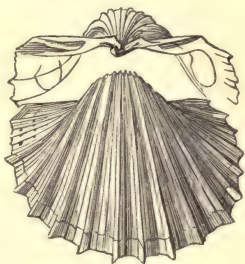


FIG. 87. — Cockle (*Cardium costatum*); one third natural size. China seas.

CLASS 3. — Gastropoda

The snails are, with rare exceptions, all univalves.²⁸ The body is coiled up in a conical shell, which is usually spiral, the whorls passing obliquely (and generally from

right to left),²⁹ around a central axis, or "columella" (Fig. 297). When the columella is hollow (perforated), the opening in the end is called the "umbilicus." When the whorls are coiled around the axis in the same plane, we have a discoidal shell, as the *Planorbis*. The mouth, or "aperture," of the shell is "entire" in most vegetable-feeding snails, and notched or produced into a canal for

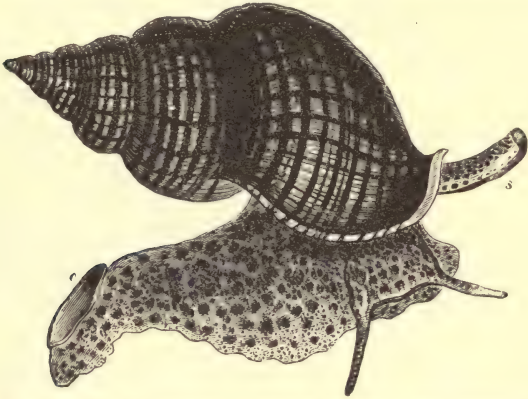


FIG. 88. — Whelk (*Buccinum*), showing operculum, *o*, and siphon, *s*.

the siphons in the carnivorous species. The former are generally land and fresh-water forms, and the latter all marine. In some gastropods, as the river snails and most sea snails, a horny or calcareous plate (*operculum*) is secreted on the foot, which closes the aperture when the animal withdraws into its shell. In locomotion, the shell is carried with the apex directed backward.

The body of most gastropods is unsymmetrical, the organs not being in pairs, but single, and on one side, instead of central. The mantle is continuous around the body, not bilobed, as in lamellibranchs. A few, as the common garden snail, have a lung; but the vast majority breathe by gills. The head is more or less distinct, and provided with two tentacles, with auditory

sacs at their bases; two eyes, which are often on stalks; and a straplike tongue (*odontophore*), covered with minute teeth (Fig. 227). The heart is situated, in the majority, on the right side of the back, and consists of an auricle and a ventricle (Fig. 243). The nervous ganglia are united into an esophageal ring or collar (Fig. 351). All, except the pteropods, move by means of a ventral disk or foot.

Gastropods are now the reigning mollusks, comprising three fourths of all the living species, and are the types of the branch. They have an extraordinary range in latitude, altitude, and depth.

Omitting a few rare and aberrant forms, we may separate the class into the following orders:—

1. *Aspidobranchia*, gastropods having a somewhat diffuse nervous system, the cerebral ganglia being wide apart, two auricles in the heart, gills plumelike, limpet (*Patella*, Fig. 105), well known to every seaside visitor, and the beautiful ear-shell (*Haliotis*, Fig. 95), frequently used for ornaments and inlaid work, the pyramidal *Trochus*, and the pearly *Turbo* (Fig. 102).

2. *Pectinibranchia*, gastropods with a somewhat concentrated nervous system, heart with a single auricle, gill bearing a single row of lamellæ and attached to the wall of the mantle. This order includes many of the most beautiful of the sea shells, the cowry (*Cypræa*) (Fig. 94), cones (Fig. 99), whelk (*Buccinum*) (Fig. 88), trumpet shell (*Triton*), volute (Fig. 101), olive, harp, cameo shell (*Cassis*) (Fig. 97), rock shell (*Murex*), spindle shell (*Fusus*) (Fig. 96), and wing shell (*Strombus*) (Fig. 103). All of these are marine. Many of them are carnivorous and have the margin of the shell notched.

3. *Opisthobranchia*. The pteropods are small, marine, floating mollusks, whose main organs of motion resemble a pair of wings or fins, coming out of the neck,

whence the common name, "sea butterflies." Many have a delicate, transparent shell. The head has six

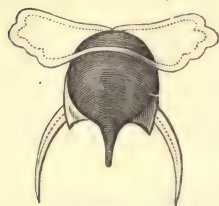


FIG. 89. — A Pteropod (*Hyalaea tridentata*). Atlantic.

appendages, armed with several hundred thousand microscopic suckers — a prehensile apparatus unequalled in complication. Pteropods occur in every latitude, but generally in mid-ocean, and in the arctic regions are the food of whales and sea birds.

The sea hare (*Aplysia*), which discharges a purple fluid, and the bubble shell (*Bulla*) belong here.

The nudibranchs or sea slugs are, for the most part, naked mollusks, only a few having a shell. They are found in all seas, from

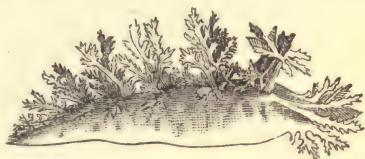


FIG. 90. — A Tritonian (*Dendronotus arborescens*). British seas.

the arctic to the torrid, generally on rocky coasts. When disturbed, most of them draw themselves up into

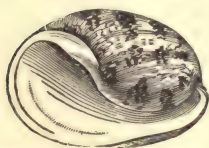


FIG. 91. — *Bulla ampulla*, or "bubble shell"; three fourths natural size. Indian Ocean.

a lump of jelly or tough skin. Examples: sea lemon (*Doris*), the beautiful *Tritonia*, and the painted *Æolis*.

4. *Pulmonata*. — These air breathing gastropods, represented by the familiar snail, have the simplest form of lung — a cavity lined with a delicate network of blood vessels,

which opens externally on the right side of the neck. This is the mantle cavity. The entrance may be closed to shut out the water in the aquatic tribes, and the hot, dry air of summer days in the land species. They are all fond of moisture, and are more or less slimy. Their shells are lighter (being thinner, and containing less

earthy matter) than those of marine mollusks, having to be carried on the back without the support of the



FIG. 92. — *A*, Land Snail (*Helix*); *B*, *C*, *D*, Slugs (*Limax*); *E*, *F*, *G*, Pond Snails (*Limnaea*, *Paludina*, and *Planorbis*).

water. Their eggs are laid singly, while the eggs of other orders are laid in chains.

They are found in all zones, but are most numerous where lime and moisture abound. All feed on vegetable matter. A few are naked, as the slug; some are terrestrial; others live in fresh water. The land snails, represented by the common *Helix*, the gigantic *Bulimus* (*Strophocheilus*), and the slug (*Limax*), are distinguished by their four "horns," the short front pair being the true tentacles, and the long hinder pair being the eye stalks. They have a sawlike upper jaw for biting leaves, and a short tongue covered with minute teeth. The pond snails.



FIG. 93. — *Bulimus* (*Strophocheilus*) *oblongus*; one half natural size. Guiana.



FIG. 94. — Cowry (*Cypraea capensis*); two thirds natural size. South Africa.

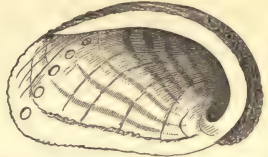


FIG. 95. — *Haliotis*, or "Pearly Ear Shell." Pacific coasts.



FIG. 96. — Spindle Shell (*Fusus colus*); one half natural size. Ceylon.

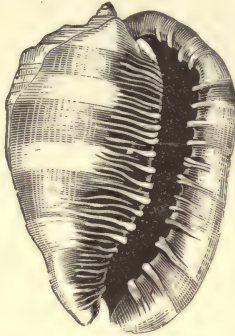


FIG. 97. — *Cassis rufa*, or "Helmet Shell;" one fourth natural size. Indian Ocean.



FIG. 98. — Auger Shell (*Terebra maculata*); one half natural size. China seas.



FIG. 99. — Cone Shell (*Conus marmoreus*); two thirds natural size. China seas.

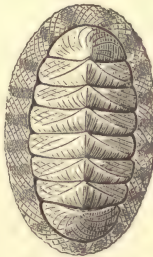


FIG. 100. — *Chiton squamosus*; one half natural size. West Indies.



FIG. 101. — Volute (*Voluta musica*); one half natural size. West Indies.

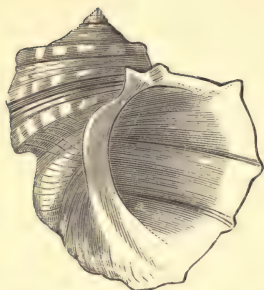


FIG. 102. — Top Shell (*Turbo marmoratus*); one fourth natural size. Australia.

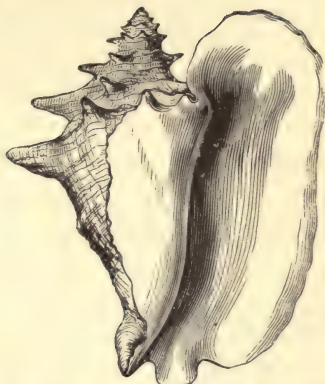


FIG. 103. — *Strombus gigas*, or "Wing Shell"; one fifth natural size. West Indies.



FIG. 104. — *Paludina*, a fresh-water snail.

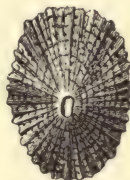


FIG. 105. — Key-hole Limpet (*Fissurella listeri*). West Indies.

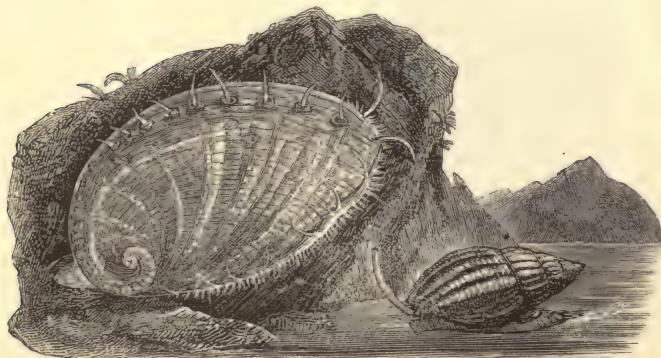


FIG. 106. — Ear Shell (*H. tuberculata*), and Dog Whelk (*Nassa reticulata*). England.

as *Limnæa* and *Planorbis*, differ in having no eye stalks, the eyes being at the base of the tentacles. They are obliged to come frequently to the surface of the water to breathe.

CLASS 4. — Cephalopoda

The cephalopods stand at the head of the branch. The head is set off from the body by a slight constriction, and furnished with a pair of large, staring eyes, a mouth armed with a rasping tongue and a parrotlike beak, and eight or more tentacles or arms. The body is symmetrical, and wrapped in a muscular mantle. The shell, if present, may be internal or external (Fig. 245).

The nervous system is more concentrated than in other invertebrates; the cerebral ganglia are partly inclosed in a cartilaginous cranium. All the five senses are present. The class is entirely marine (breathing by plumelike gills on the sides of the body), and carnivorous. The naked species are found in every sea. Those with chambered shells (as *Nautilus*, *Ammonites*, and *Orthoceras*) were once very abundant; more than two thousand fossil species are known, but only three species have been found living.

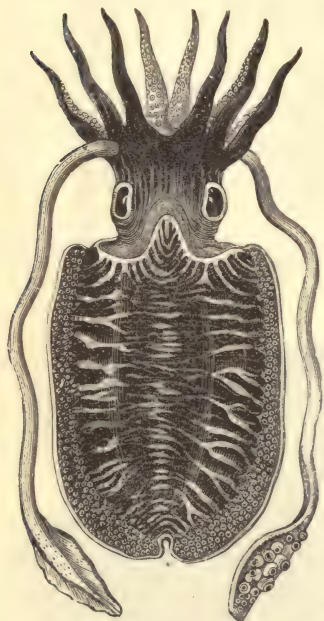


FIG. 107. — Cuttlefish (*Sepia officinalis*); one fifth natural size. Atlantic coasts.

1. *Dibranchs*. — These are the most active of mollusks, and the tyrants of the lower tribes. Among them are the largest of invertebrate animals. They are naked, having

no external shell covering the body, but usually a horny or calcareous part within. They have a distinct head, prominent eyes, horny mandibles, eight or ten arms furnished with suckers, two gills, a complete tubular funnel, and an ink bag containing a peculiar fluid (*sepia*), of intense blackness, with which the water is darkened to facilitate escape. They have the power of changing color, like the chameleon. They crawl with their arms on the bottom of the sea, head downward, and also swim backward or forward, usually with the back downward, by means of fins, or squirt themselves backward by forcing water forward through their breathing funnels.

The paper nautilus (*Argonauta*) and the poulpe (*Octopus*) have eight arms. The female argonaut secretes a thin, unchambered shell for carrying its eggs. The squid (*Loligo*) and cuttlefish (*Sepia*) have ten arms, the additional pair being much longer than the others. Their eyes are movable, while those of the argonaut and poulpe are fixed. The squid, so much used for bait for cod, has an internal horny "pen," and the cuttle has a spongy, calcareous "bone." The extinct *Belemnites* had a similar structure. Squid have been found with a body eleven feet and arms thirty-nine feet long, and parts of others still larger—as much as seventy feet in total length.

2. *Tetrabranchs*.—This group is characterized by the possession of four gills, forty or more short tentacles,

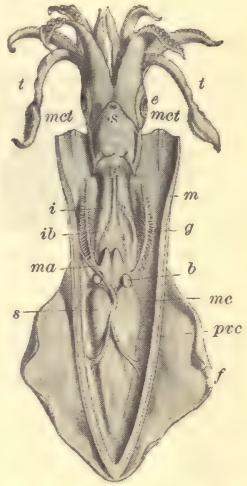


FIG. 108. — (*Loligo Pealii*) with the mantle cut open: *b*, branchial heart; *e*, eye; *f*, fin; *g*, gill; *i*, intestine; *ib*, ink bag; *m*, cut edge of mantle; *ma*, mantle artery; *mc*, mantle cavity; *mct*, mantle cartilages; *pvc*, posterior vena cava; *s*, siphon; *t*, tentacles with sucking disks; *vs*, visceral sac.

and an external, chambered shell. The partitions, or septa, of the shell are united by a tube called "siphun-

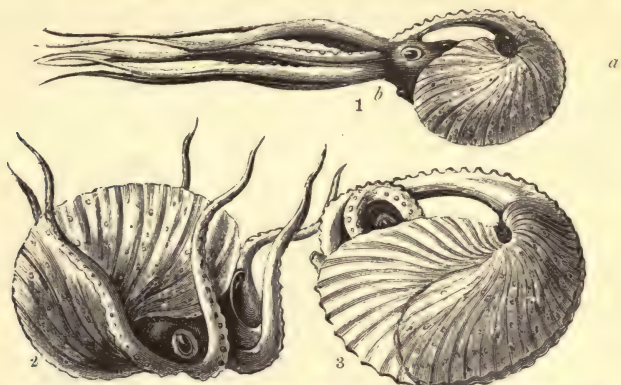


FIG. 109. — Female paper nautilus (*Argonauta argo*): 1, swimming toward *a* by ejecting water from funnel, *b*; 2, crawling on the bottom; 3, coiled within its shell, which is one fourth natural size. Mediterranean.

cle," and the animal lives in the last and largest chamber.³⁰ The living nautilus has a smooth, pearly

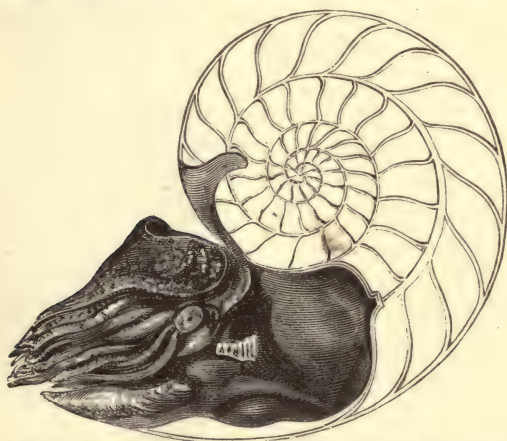


FIG. 110. — Pearly nautilus, with shell bisected; one half natural size. Indian Ocean.

shell, a head retractile within the mantle or "hood," and calcareous mandibles, well fitted for masticating

crabs, on which it feeds. The pearly nautilus dwells in the Indian Ocean, crawling on the bottom at moderate depths; and, while the shell is well known, only a few specimens, comparatively, of the animal have ever been obtained.

Branch XII. — CHORDATA

This grand division includes the most perfect animals, or such as have the most varied functions and the most perfect and complex organs. Besides the unnumbered host of extinct forms, there are about twenty-five thousand living species, widely differing among themselves in shape and habits, yet closely allied in the grand features of their organization, the general type being endlessly modified.

The fundamental distinctive character of typical chordates is the separation of the main mass of the nervous system from the general cavity of the body. A transverse section of the body exhibits two cavities, or tubes — the dorsal, containing the cerebrospinal nervous system; the ventral, inclosing the alimentary canal, heart, lungs, and a double chain of ganglia, or sympathetic system. This

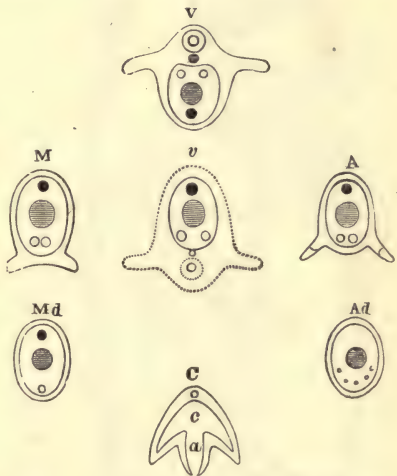


FIG. 111. — Ideal plans of the branches. *V*, transverse section of vertebrate type; *v*, the same inverted. *M*, transverse section of molluscoid type; and *Md*, of molluscoid. *A* and *Ad*, transverse sections of articulate type, high and low. *C*, longitudinal section of coelenterate type; *a*, alimentary canal; *c*, body cavity. In the other figures, the alimentary canal is shaded, the heart is black, and the nervous cords are open rings.



FIG. 112. — Diagram of circulation in the higher vertebrates: 1, heart; 2, lungs; 3, head and upper extremities; 4, spleen; 5, intestine; 6, kidney; 7, lower extremities; 8, liver. (From Dalton's "Physiology.")

ventral, or hemal, cavity corresponds to the whole body of an invertebrate; while the dorsal, or neural, is mainly additional.

Vertebrates are also distinguished by an internal, jointed skeleton, endowed with vitality, and capable of growth and repair. During embryo life it is represented by the notochord; but in the higher forms this is afterward replaced by a more highly developed vertebral column of cartilage or bone. The column and cranium are never absent in the Craniata; other parts may be wanting, as the ribs in frogs, limbs in snakes, etc. The limbs are never more than four, and are always articulated to the hemal side of the body, while the legs of invertebrates are developed from the neural side. The muscles moving the limbs are attached to the endo-skeleton.

The circulation of the blood is complete, the arteries being joined to the veins by capillaries, so that the blood never escapes into the visceral cavity as in the

invertebrates. All have a portal vein, carrying blood through the liver; all have lacteals and lymphatics. The blood is red, and contains both kinds of corpuscles. The teeth are developed from the dermis, never from the cuticle, as in mollusks and arthropods; the jaws move vertically, and are never modified limbs. Except in the lowest forms the liver and kidneys are always present. The respiratory organs are either gills or lungs, or both. Vertebrates are the only animals which breathe through the mouth cavity.

The nervous system has two marked divisions: the cerebrospinal, presiding over the functions of animal life (sensation and locomotion); and the sympathetic, which partially controls the organic functions (digestion, respiration, and circulation). In no case does the gullet pass through the nervous system, as in invertebrates, and the mouth opens on the side opposite to the brain. Except in the lowest members of this group probably none of the five senses is ever altogether absent. The form of the brain is modified by the relative development of the various lobes. In the lower vertebrates, the cerebral hemispheres are small — in certain fishes they are actually smaller than the optic lobes — in the higher, they nearly or quite overlap both olfactories and cerebellum. The brain may be smooth, as in most of the cold-blooded animals, or richly convoluted, as in man.

There is no skull in *Amphioxus*. In the *Cyclostomata* and *Elasmobranchii* it is cartilaginous. In other fishes it is cartilage overlaid with bone. In amphibians and reptiles, it is mingled bone and cartilage. In birds and mammals, it is mainly or wholly bony. The human skull contains fewer bones than the skull of most animals, excepting birds. The skull of all vertebrates is divisible into two regions: the cranium, or brain case,

and the face. The size of the cranial capacity, compared with the area of the face, is generally the ratio of intelligence. In the lower orders, the facial part is enormously predominant, the eye orbits are directed outward, and the occipital condyles are nearly on a line with the axis of the body. In the higher orders, the face becomes subordinate to the cranium, the sensual to the mental, the eyes look forward, and the condyles approach the base of the cranium. Compare the "snouty" skull of the crocodile, and the almost vertical profile of civilized man. A straight line drawn from the middle of the ear to the base of the nose, and another from the forehead to the most prominent part of the upper jaw, will include what is called the *facial angle*, which roughly gives the relation between the two regions, and the intellectual rank of the animal.³¹ In the cold-blooded vertebrates the brain does not fill the cranium; while in birds and mammals a cast of the cranial cavity well exhibits the general features of the cerebral surface.³²

All higher vertebrates are single and free. Mammals bring forth their young alive, the young before birth deriving their nourishment directly from the mother (*viviparous*). In almost all the others the nourishment is stored up in the egg, which is laid before hatching (*oviparous*), or is retained in the mother until hatched (*ovoviviparous*), as in some reptiles and fishes.

Of the branch Chordata there are three subbranches: *Adelochorda*, *Urochorda*, and *Vertebrata*. The first includes *Balanoglossus*, a wormlike creature regarded by some zoölogists as being related to the backboned animals, together with two other forms (*Rhabdopleura* and *Cephalodiscus*) whose affinities are less plain. The second includes the tunicates, while the great mass of the Chordata belong in the third subdivision of the branch.

The group *Vertebrata* consists of two divisions, the first, *Acrania*, including the skull-less forms, *e.g.*, the lancelet (*Amphioxus*), while the second, and much larger division, *Craniata*, consists of six great classes, *Cyclostomata*, *Pisces*, *Amphibia*, *Reptilia*, *Aves*, and *Mammalia*. The first four are "cold-blooded," the other two are "warm-blooded." Cyclostomes, fishes, and amphibians have gills during the whole or a part of their lives, while the rest never have gills. Fishes and amphibians in embryo have neither amnion nor allantois, while the animals in the last three classes are provided with both.

The skull bearing vertebrates may be grouped into three provinces.

Cyclostomes, fishes, and amphibians agree in having gills or gill pouches, in wanting amnion and allantois, and in possessing nucleated red blood corpuscles (*Ichthyopsida*).

Birds and reptiles agree in having no gills, but both amnion and allantois, in the articulation of the skull with the spine by a single condyle, in the development from the skin of feathers or scales, and in having oval, nucleated, red corpuscles (*Sauropsida*).

Mammals differ from birds and reptiles in having two occipital condyles, and their red blood corpuscles are not nucleated³³ (*Mammalia*).

SUBBRANCH AND CLASS I. — *Adelochorda*

The principal representative of this class is *Balanoglossus*, a soft-bodied, wormlike animal, one inch to six inches long, which lives in the sand and mud, along the Mediterranean coast,

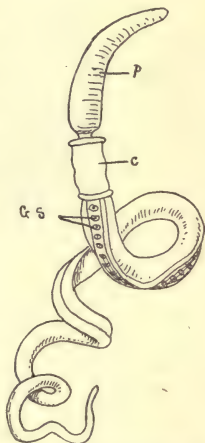


FIG. 113. — *Balanoglossus*,
p, proboscis; c, "collar";
gs, gill slits. Enlarged.

and is also found in the English Channel and Chesapeake Bay. It is placed among the Chordata because it is regarded by some zoölogists as having a notochord, gill slits, and a dorsal nerve cord. All of these are so rudimentary that the position of the animal in the scheme of classification is not yet definitely determined. Other structural and developmental features ally *Balanoglossus* to the annelids, and the echinoderms, for which reason the animal may be looked upon as an intermediate form between these groups and the *Chordata*.

SUBBRANCH AND CLASS 2.—Urochorda

The tunicates form a small and singular group of animals now regarded as being the degenerate descendants of primitive Chordata.



FIG. 114. — An ascidian.

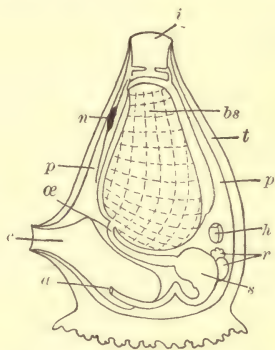


FIG. 115. — Diagram of a tunicate. *i*, inhalant opening; *bs*, branchial sac; *t*, "tunic"; *p*, peribranchial cavity; *æ*, esophagus; *s*, stomach; *a*, anus; *c*, cloaca; *h*, heart; *r*, reproductive organs; *n*, nerve ganglion.

They occur both as fixed and as free swimming forms, and as single individuals as well as chains or groups of individuals. The most common forms (the solitary *Ascidians*) are inclosed in a leathery, elastic bag, one end of which is fastened to the rocks, while the other has two orifices, for the inlet and exit of a current of water for nutrition and respiration.

They are without head, feet, arms, or shell. Indeed, few animals seem more helpless and apathetic than these apparently shapeless beings. The tubular heart exhibits the curious phenomenon of reversing its action at brief intervals, so that the blood oscillates backward and forward in the same vessels.

Another peculiarity is the presence of cellulose in the skin. The water is drawn by cilia into a branchial sac, an enlargement of the first part of the intestine, whence it escapes through openings in the sides, to the excurrent orifice, while the particles of food drawn in with the water are retained and passed into the intestine. The larva is active for a few hours, swimming by means of a long tail. It looks like a minute tadpole, and has a notochord and

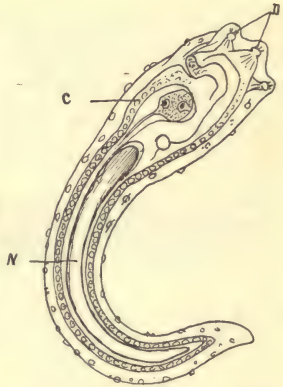


FIG. 116. — Larval stage of a tunicate, showing the notochord, *n*; the spinal cord, *c*; and the sucking disks, *d*, by which the larva becomes attached previous to changing to the adult condition. Much magnified.

a nervous system closely resembling those of a vertebrate. Afterward it attaches itself by the head, the tail is absorbed, and the nervous system is reduced to a single small ganglion. Thus the animal, whose larval structure is that of a vertebrate (since it possesses a dorsal nerve cord, a notochord in the dorsal region, and gill slits opening to the exterior), degenerates in its adult stage into an invertebrate.

Besides developing from fertilized eggs, the tunicates also multiply by the process of budding. In *Salpa* and some other kinds, alternation of generations takes place. All species are marine and some form colonies.

SUBBRANCH 3. — Vertebrata

DIVISION A. — Acrania

Vertebrates without a skull.

CLASS. — Pharyngobranchii

The Acrania are represented by the singular animal *Amphioxus* or lancelet. It is about two inches long, semitransparent, without skull, limbs, brain, heart, or red corpuscles. It has for a skeleton a notochord only. It breathes by very numerous gill arches, without fringes,

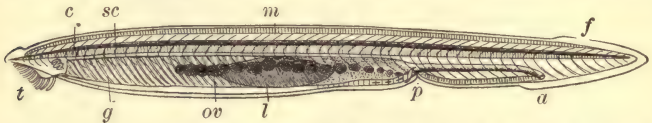


FIG. 117. — Lancelet (*Amphioxus*). Notochord, *c*; spinal cord, *sc*; oral tentacles, *t*; gills, *g*; ovary, *ov*; liver, *l*; anus, *a*; pore of branchial chamber, *p*; muscle plates, *m*; tail fin, *f*. Natural size.

and the water is drawn in by cilia, which line the gill slits. The embryo develops into a gastrula closely resembling that of the invertebrates. The animal lives in the sandy bottom of shallow parts of the ocean, and has been found in the Mediterranean Sea, in the Indian Ocean, and on the coasts of North America and South America.

DIVISION B. — Craniata

Vertebrates with a distinct skull.

CLASS I. — Cyclostomata

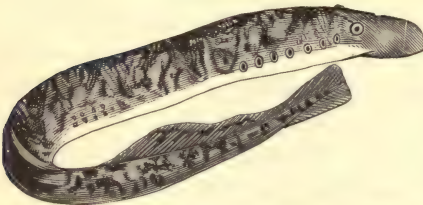


FIG. 118. — Lamprey (*Petromyzon marinus*). Atlantic.

The lampreys and hagfish have a persistent notochord, a cartilaginous skull, no lower jaw, a round, suctional mouth, horny

teeth, one nasal organ, no scales, limbs, or gill arches. The gills are in pouches which open separately. They are found both in salt water and in fresh water.

CLASS II. — Pisces

Fishes fall far behind the rest of the typical craniates in strength, intelligence, and sensibility. The eyes, though large, are almost immovable, bathed by no tears, and protected by no lids. Dwelling in the realm of silence, ears are little needed, and such as they have are without external parts, the sound being obliged to pass through the cranium. Taste and smell are blunted, and touch is nearly confined to the lips.

The class yields to no other in the number and variety of its forms. It includes nearly one half of all the vertebrated species. So great is the range of variation, it is difficult to frame a definition which will characterize all the finny tribes. It may be said, however, that fishes are the only backboned animals having median fins (as dorsal and anal) supported by fin rays, and whose limbs (pectoral and ventral fins) do not exhibit that threefold division (as thigh, leg, and foot) found in most other craniates.

The form of fishes is admirably adapted to the element in which they live and move. Indeed, Nature nowhere presents in one class such elegance of proportions with such variety of form and beauty of color. The head is disproportionately large, but pointed to meet the resistance of the water. The neck is wanting, the head being a prolongation of the trunk (Fig. 320). The viscera are closely packed near the head, and the long, tapering trunk is left free for the development of muscles which are to move the tail—the instrument of locomotion (Fig. 321). The biconcave vertebræ, with intervening

cavities filled with elastic gelatin, are designed for rapid and versatile movements. The body is either naked, as in the bullhead (*Ameiurus*), or covered with polished, overlapping scales, as in the perch. Rarely, as in the sturgeon, it is defended by bony plates, or by

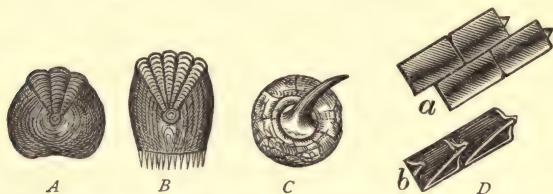


FIG. 119. — Scales of fishes: *A*, cycloid scale (*Salmon*); *B*, ctenoid scale (*Perch*); *C*, placoid scale (*Ray*); *D*, ganoid scales (*Amblypterus*) — *a*, upper surface; *b*, under surface, showing articulating processes.

minute, hard spines, as in the shark. Scales with smooth, circular outline are called *cycloid*; those with notched or spiny margins are *ctenoid*. Enameled scales are *ganoid*, and those with a sharp spine, like those of the shark, are *placoid*.

The vertical fins (dorsal, anal, and caudal) are peculiar to fishes. The dorsal vary in number, from one, as in

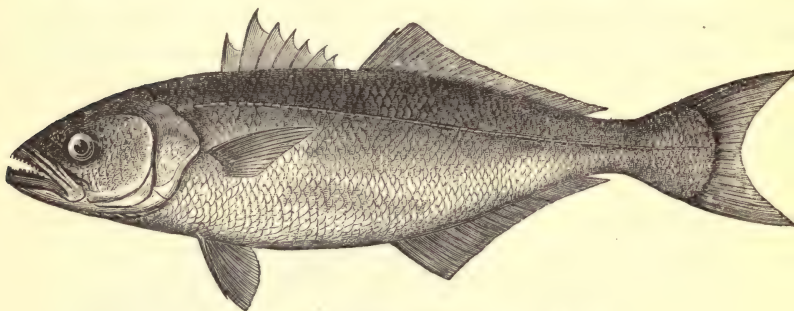


FIG. 120. — Bluefish (*Pomatomus saltatrix*). All seas.

the herring, to three, as in the cod; and the first dorsal may be soft, as in the trout, or spiny, as in the perch. If the dorsals are cut off, the fish reels to and fro. The

caudal may be homocercal, as in ordinary species; or heterocercal, as in sharks. In ancient heterocercal fishes, the tail was frequently vertebrated. The pectoral and ventral fins stand for the fore and hind limbs of other vertebrates. As the specific gravity of the body is greater than that of the water, most fishes are provided with an air bladder, which is an outgrowth from the esophagus. This is absent in such as grovel at the bottom, as the rays, and in those, like the sharks, endowed with compensating muscular power.

Fishes have no prehensile organ besides the mouth. Both jaws are movable. The teeth are numerous, and



FIG. 121. — Salmon (*Salmo salar*). Both hemispheres.

may be recurved spines, as in the pike; flat and triangular, with serrated edges, in the shark; or flat and tessellated in the ray (Fig. 230). They feed principally on animal matter. The digestive tract is relatively shorter than in other vertebrates. The blood is red, and the heart has rarely more than two cavities, an auricle and a ventricle, both on the venous side. Ordinary fishes have four gills, which are covered by the *operculum*, and the water escapes from an opening behind this. In sharks there is no *operculum*, and each gill pouch opens separately. The brain consists of several ganglia placed one behind the other, and occupies but a small part of the cranial cavity (Fig. 336). Its average weight to the

rest of the body may be as low as 1 to 3000. The eggs of bony fishes are naked and multitudinous, sometimes numbering millions in a single spawn; those of the sharks are few, and protected by a horny shell (Fig. 360).

There are about thirteen thousand species of fishes, of which over two thirds are Teleostomi. There are three principal subclasses of Pisces.

SUBCLASS I. — Elasmobranchii

These have a cartilaginous skeleton, and a skin naked or with placoid scales. The gill openings are uncovered; and the mouth is generally under the head. The



FIG. 122. — Shark (*Carcharias vulgaris*). Atlantic.

ventral fins are placed far back; the pectorals are large, in the rays enormously developed; and the tail is heterocercal. Such are the sharks, rays, and dogfishes. They are all marine. The largest shark found, and therefore the largest fish, measured forty feet in length.

SUBCLASS II. — Teleostomi

This subclass includes all of the common fishes having a bony endoskeleton and a scaly exoskeleton. The skull is extremely complicated; the upper and lower

jaws are complete, and the gills are comblike or tufted, and covered by an operculum. The tail is homocercal except in the "ganoids," as the sturgeon and garpike, in which it is heterocercal or unevenly lobed; the other fins are variable in number and position. In the soft-finned fishes, the ventrals are absent, as in the eels; or attached to the abdomen, as in the salmons, herrings,



FIG. 123. — Thornback (*Raia clavata*). European seas.

piques, and carps; or placed under the throat, as in the cod, haddock, and flounder. In the spiny-finned fishes, the ventrals are generally under or in front of the pectorals, and the scales ctenoid, as in the perches, mullets, and mackerels.

The so-called "ganoids" have the body covered with enameled scales or bony plates.



FIG. 124. — Garpike (*Lepidosteus osseus*). Lake Ontario.

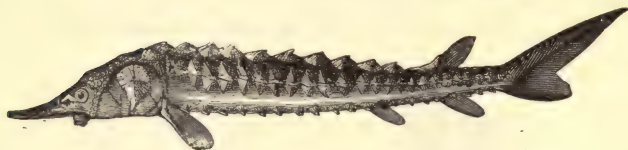


FIG. 125. — Sturgeon (*Acipenser sturio*). Atlantic coast.



FIG. 126. — Catfish, or Horned Pout (*Ameiurus nebulosus*). American rivers.



FIG. 127. — Cod (*Gadus callarias*). Atlantic coast.

SUBCLASS III. — Dipnoi

These fishes connect the class with the Amphibia. They have an eel-like body sometimes four or five feet long, covered with cycloid scales; an embryonic notochord for a backbone; long, ribbonlike pectoral and ventral fins, set far apart; two incompletely separated auricles, and one ventricle; and, besides gills, a cellular air bladder, which is used as a lung.

They live in muddy or stagnant water in which there is little oxygen for respiration, not enough to be obtained

by the gills alone, so these fishes occasionally come to the surface and take air into the lungs. Lungfishes feed upon the small animals captured among the water plants.

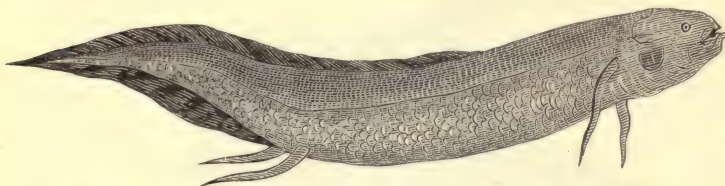


FIG. 128. — *Protopterus annectens*; one fourth natural size. African rivers.

The representatives are *Ceratodus* from Australia, *Protopterus* from Africa, and *Lepidosiren* from Brazil.

CLASS III. — Amphibia

These cold-blooded vertebrates are distinguished by having gills when young, and usually true lungs when adult. They have no fin rays, and the limbs, when present, have the same divisions as those of higher animals. The skin is soft, and generally naked, and the skeleton is ossified. The skull is flat, and articulates with the spinal column by two condyles. There is no distinct neck; and the ribs are usually small or wanting (Fig. 284). The heart consists of two auricles and one ventricle (Fig. 273). In the course of development nearly all undergo metamorphosis upon leaving the egg, passing through the "tadpole" state (Fig. 370). They commence as water-breathing larvæ, when they resemble fishes in their respiration, circulation, and locomotion. In the lowest forms, the gills are retained through life; but all others have, when mature, lungs only (Fig. 282), the gills disappearing. The cuticle is frequently shed, the mode varying with the habits of the species.³⁴ The common frog, the type of this class, stands intermediate

between the two extremes of the vertebrate series; no fundamental part is excessively developed.

There are about seven hundred living species, grouped in three orders: —

1. *Urodela*, characterized by retaining the tail throughout life, and in usually having two pairs of limbs approximately equal in size.

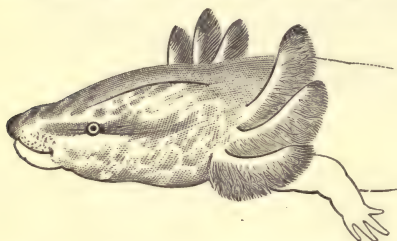


FIG. 129. — Head and gills of *Necturus*. Cayuga Lake. Copyright, 1901, by N. Y. Zoölogical Society.

In this group are the *Proteus* of Austria and *Necturus* of the Eastern United States, both of which retain their gills; *Amphiuma* of North America, and the salamanders and

newts, in which the gills are lost in the adult, though the former retains a gill slit as an evidence of their presence in the larval stage.³⁵

2. *Anura* include all the well-known amphibians which are tailless in the adult stage, as frogs and toads. They have a moist, naked skin, ten vertebræ, and no ribs. They breathe by swallowing the air. They have four limbs — the hinder



FIG. 130. — Red Salamander (*Spelerpes ruber*). United States.

the longer, and the first developed. They have four fingers and five toes. The tongue is long, and, fixed by its anterior end, it can be rapidly thrown out as an organ of prehension.³⁶ The eggs are laid in the water enveloped in a glairy mass; and the tadpoles resemble the urodelans till both gills and tail are absorbed, no gill slit persisting. Frogs (*Rana*) have teeth in the

upper jaw, and webbed feet ; toads (*Bufo*) are higher in rank, and have neither teeth nor fully webbed feet.



FIG. 131. — Bullfrog (*Rana*). North America.

The former have been known to live sixteen years, and the latter thirty-six.



FIG. 132. — *Proteus anguinus*. Europe.

3. *Gymnophiona* have neither tail nor limbs nor gill slit, a snakelike form, minute scales in the skin, and well-

developed ribs. They are confined to the tropics, and are subterranean in habit.

CLASS IV. — Reptilia

These air-breathing, cold-blooded vertebrates are distinguished from all fishes and amphibians by never having gills, and from birds by being covered with horny scales or bony plates. The skeleton is never cartilaginous (Fig. 310); and the skull has one occipital condyle. The vertebræ are ordinarily concave in front; and the ribs are well developed. With few exceptions, all are carnivorous; and teeth are generally present (Figs. 231, 235), except in the turtles, where a horny sheath covers the jaws. The teeth are never fastened in sockets, except in crocodiles (Fig. 224). The jaws are usually very wide. The heart has three chambers (Fig. 273), save in crocodiles, where the ventricle is partially partitioned. But in all cases a mixture of arterial and venous blood is circulated. The lungs are large, and coarsely cellular (Fig. 281). The limbs, when present, are provided with three or more fingers as well as toes.

There are about three thousand species of living reptiles, and of these there are three main orders: the first has horny scales, the others have bony plates combined with scales.

1. *Squamata*, including the lizards and the snakes. The lizards (*Lacertilia*) may be likened to snakes provided with four limbs, each having five digits.³⁷ The body is covered with horny scales. All have teeth, which are simple in structure; and the halves of the lower jaw are firmly united in front, while those of snakes are loosely tied together by ligaments. Nearly all have a breastbone, and the eyes (save in the gecko) are furnished with movable lids. In the common lizards and chameleon, the tongue is extensile. The tail is usually long, and in

some cases each caudal vertebra has a division in the middle, so that the tail, when grasped, breaks off at one of these divisions. The chameleon has a prehensile tail. The iguana is distinguished by a dewlap on the throat and a crest on the back. Except some of the monitors of the Old World, all the lizards are terrestrial.



FIG. 133. — Lizard (*Lacerta*).

The snakes (*Ophidia*) are characterized by the absence of visible limbs;³⁸ by the great number of vertebræ, amounting to over four hundred in the great serpents; by a corresponding number of ribs, but no sternum; and no true eyelids, the eyes being covered with a transparent skin. The tongue differs from that of nearly all other reptiles in being bifid and extensile. The mouth is very dilatable. The skin is frequently shed, and always by reversing it. Snakes make their way on land or in water with equal facility.

As a rule, the venomous snakes, as vipers and rattlesnakes, are distinguished by a triangular head covered

with small scales; a constriction behind the head; two or more fangs, and few teeth; small eyes, with vertical

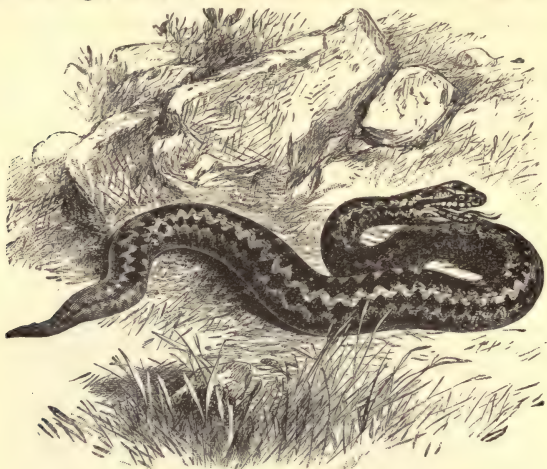


FIG. 134. — Adder, or viper (*Vipera berus*). England.

pupil; and short, thick tail. In the harmless snakes, the head gradually blends with the neck, and is covered with plates; the teeth are comparatively numerous

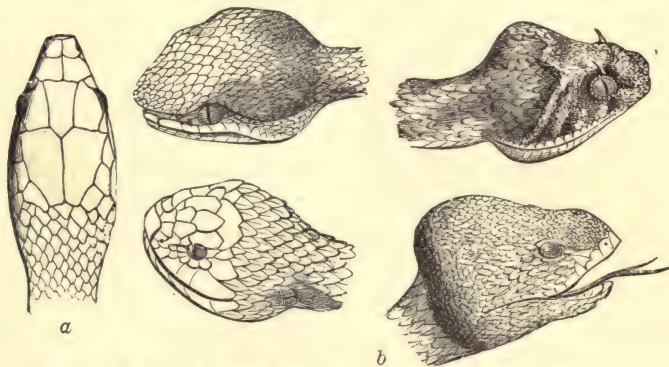


FIG. 135. — *a*, Head of a harmless snake (upper view); *b*, heads of various venomous snakes.

in both jaws; the pupil is round, and the tail tapering. This rule, however, has many exceptions.

2. *Chelonia*, or tortoises and turtles, are of anomalous structure. The skeleton is external, so as to include not only all the viscera, but also the whole muscular system, which is attached internally; and even the limbs are

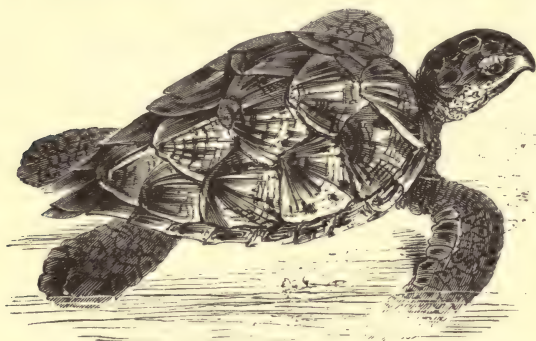


FIG. 136. — Hawkbill turtle (*Chelone imbricata*). Tropical Atlantic.

inside, instead of outside, the thorax. The exoskeleton unites with the endoskeleton, forming the *carapace*, or case, in which the body is inclosed. The exoskeleton consists of horny plates, known as “tortoise shell” (in

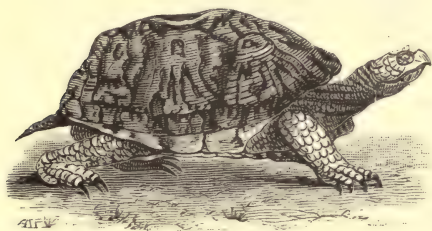


FIG. 137. — Box tortoise (*Terrapene carolina*).
United States.

the soft tortoises, *Aspidonectes*, this is wanting), and of dermal bones, united to the expanded spines of the vertebræ and to the ribs, making the walls of the carapace (Fig. 312).

The ventral pieces form the *plastron*.³⁹ All are toothless. There are always four stout legs; and the order furnishes the only examples of vertebrates lower than birds that really walk, for lizards and crocodiles wriggle,

and drag the body along. There are no teeth, but a horny beak. The eggs are covered with a calcareous shell.

The sea turtles, as the edible green turtle and the hawksbill turtle, which furnish the "tortoise shell" of commerce, have the limbs converted into paddles. The fresh-water forms, represented by the snapping turtle (*Chelydra*), are amphibious, and have palmated feet. Land tortoises (*Testudo*) have short, clumsy limbs, fitted for slow motion on the land; the plastron is very broad, and the carapace is arched (while it is flattened in the aquatic species), and head, legs, and tail can be drawn within it. The land and marine species are vegetable feeders; the others, carnivorous.

3. *Crocodylia*, the highest and largest of reptiles, have also two exoskeletons — one of horny scales (epidermal),



FIG. 138. — Alligator (*A. mississippiensis*). Southern States.

and another of bony plates (dermal). The bones of the skull are firmly united, and furnished with numerous teeth, implanted in distinct sockets. The lower jaw extends back of the cranium. The heart has four cavities, but the pulmonary artery and aorta communicate with each other, so that there is a mixture of venous and arterial blood. They have external ear openings, closed by a flap of the skin, and eyes with movable lids; a muscular gizzard; a long, compressed

tail; and four legs, with feet more or less webbed, and having five toes in front and four behind. The existing species are confined to tropical rivers, and are carnivorous. The eggs are covered with a hard shell.

There are three representative forms: the gavial of the Ganges, remarkable for its long snout and uniform teeth; the crocodiles, mainly of the Old World, whose teeth are unequal, and the lower canines fit into a notch in the edge of the upper jaw, so that it is visible when the mouth is closed; and the alligators of the New World, whose canines, in shutting the mouth, are concealed in a pit in the upper jaw. The toes of the gavials and crocodiles are webbed to the tip; those of the alligators are not more than half webbed.

In the mediæval ages of geological history, the class of reptiles was far more abundantly represented than now. Among the many forms which geologists have unearthed are numerous gigantic saurians, which cannot be classified with any of the four living orders. Such are the *Ichthyosaurus*, *Plesiosaurus*, *Pterodactylus*, *Megalosaurus*, and *Iguanodon*.

CLASS V. — **Aves**

Birds form the most clearly defined class in the whole animal kingdom, and in some respects are the most highly specialized of the craniata. The eagle and hummer, the ostrich and duck, widely as they seem to be separated by size, form, and habits, still exhibit one common type of structure. On the whole, birds are more closely allied to reptiles than to mammals. In number, they approach the fishes, ornithologists having determined eight thousand species, or more.

A bird is an air-breathing, egg-laying, warm-blooded, feathered vertebrate, with two limbs (legs) for perching, walking, or swimming, and two limbs (wings) for flying

or swimming. Organized for flight, it is gifted with a light skeleton, very contractile muscular fibers, and a respiratory system of the highest development.

The skeleton is more compact than those of reptiles and mammals, at the same time that it is lighter, and the bones are harder and whiter. It contains fewer bones than usual, many parts being anchylosed together, as the skull bones, the dorsal vertebræ, and bones of the tarsus and metatarsus. The lumbar vertebræ are united to the ilia. The neck is remarkably long (containing from nine to twenty-four vertebræ) and flexible, enabling the head to be a most perfect prehensile organ. The ribs are generally jointed in the middle, as well as with the backbone and sternum. The last, where the muscles of flight originate, is highly developed. The skull articulates with the spinal column by a single condyle, and with the lower jaw, not directly, as in mammals, but through the intervention of a separate bone, as in reptiles (Fig. 313).

All birds have four limbs, while every other vertebrate class shows exceptions. The fore limbs are fitted for flight. They ordinarily consist of nine separate bones, and from the hand, fore arm, and humerus are developed the primary, secondary, and tertiary feathers of the wing. The hind limbs are formed for progression — walking, hopping, running, paddling, and also for perching and grasping. The modifications are more numerous and important than those of the bill, wing, or tail. There are twenty bones ordinarily, of which the tibia is the principal; but the most characteristic is the tarsometatarsus, which is a fusion of the lower part of the tarsus with the metatarsus. The rest of the tarsus is fused with the tibia. The thigh is so short that the knee is never seen outside of the plumage; the first joint visible is the heel.⁴⁰ Most birds have four toes

(the external or "little" toe is always wanting); many have three, the *hallux*, or "big" toe, being absent; while the ostrich has but two, answering to the third and fourth. The normal number of phalanges, reckoning from the hallux, is 2, 3, 4, 5. The toes always end in claws.

Birds have neither lips nor teeth, epiglottis nor diaphragm. The teeth are wanting, because a heavy masticating apparatus in the head would be unsuitable for flight. The beak, crop, and gizzard vary with the food. It is a peculiarity of all birds, though not confined to them, that the generative products and the refuse of digestion are all discharged through one common outlet.

The sole organs of prehension are the beak and feet. The circulation is double, as in mammals, starting from a four-chambered heart (Fig. 273). Respiration is more complete than in other vertebrates. The lungs are fixed, and communicate with air sacs in various parts of the body, as along the vertebral column, and also with the interior of many bones, as the humerus and femur, which are usually hollow and marrowless.⁴¹ Both brain and cord are much larger relatively than in reptiles (Fig. 338); the cranium

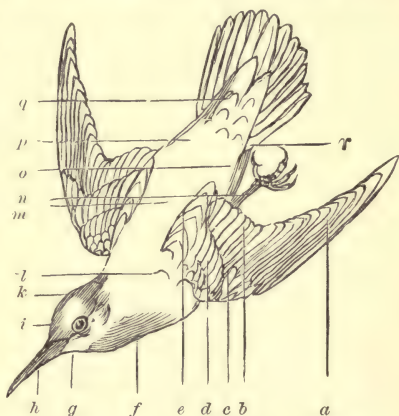


FIG. 139. — Principal parts of a bird: *a*, primaries; *b*, secondaries; *c*, spurious wing; *d*, wing coverts; *e*, tertaries; *f*, throat, or jugulum; *g*, chin; *h*, bill; the meeting line between the two mandibles is the commissure; the ridge on the upper mandible is called culmen; that of the lower, gonys; the space between the base of the upper mandible and the eye is the lore; *i*, forehead; *k*, crown; *l*, scapular feathers; *m*, back; *n*, metatarsus, often called tarsus or tarsometatarsus; *o*, abdomen; *p*, rump; *q*, upper tail coverts; *r*, lower tail coverts.

is larger in proportion to the face; and the parts of the brain are not situated in one plane, one behind the other. The cerebrum is round and smooth, and the cerebellum single-lobed. The ears resemble those of crocodiles; but the eyes are well developed, and protected by three lids. They are placed on the sides of the head, and the pupil is always round. The sexes generally differ greatly in plumage, in some cases more widely than two distinct species, but the coloration of either sex of any one species is very constant.

There are two divisions of living birds.

DIVISION A.—*Ratitæ* (*Cursores*)

This small and singular group is characterized by having no keel on the breastbone, rudimentary wings, feathers with disconnected barbs, and stout legs. The African ostrich has two toes, the cassowary three, and the apteryx four.



FIG. 140. — African Ostrich (*Struthio camelus*).

Its representatives are the ostrich (*Struthio*) of Africa and Arabia, South American ostrich (*Rhea*), cassowary (*Casuarus*) of the East Indian Archipelago and Australia, emu (*Dromæus*) of Australia, and *Apteryx*, or kiwikiwi, of New

Zealand. Besides these, there are extinct gigantic forms

from Madagascar (*Æpyornis*) and from New Zealand, the moa (*Dinornis*). This singular geographical distribution, like that of the Dipnoi and marsupials, shows that the group was once widely spread over the earth, but is now greatly restricted in area.

DIVISION B. — *Carinatæ*

Birds which, with rare exceptions, *e.g.*, the Penguins, have a keeled sternum, and developed functional wings.

Of the birds composing this division, some live mainly in the water, others on the land, while still others spend a considerable part of their lives on the wing. Their bodily structure is, consequently, modified to suit their mode of life. Hence, they may be broadly grouped into aquatic, terrestrial, and aerial birds.

A. AQUATIC BIRDS. — Specially organized for swimming; the body flattened, and covered with water-proof clothing — feathers and down; the legs short (the knees being wholly withdrawn within the skin of the body), and set far apart and far back; the feet webbed, and hind toe elevated or absent. The legs are always feathered to the heel at least. They are the only birds whose neck is sometimes longer than the legs.

Examples, penguins, ducks, petrels, and gulls.

B. TERRESTRIAL BIRDS. — This group exhibits great diversity of structure; but all agree in being especially terrestrial in habit, spending most of the time on the ground, not on trees or the water, although many of them fly and swim well. The legs are long or strong, and the knee is free from the body. The hind toe, when present, is small and elevated. Such birds are the storks, plovers, and turkeys.

C. AËRIAL BIRDS. — This highest and largest group includes all those birds whose toes are fitted for grasping or perching, the hind toe being on a level with the rest.

The knee is free from the body, and the leg is generally feathered to the heel. The wings are adapted for rapid or long flight, and they hop, rather than walk, on the

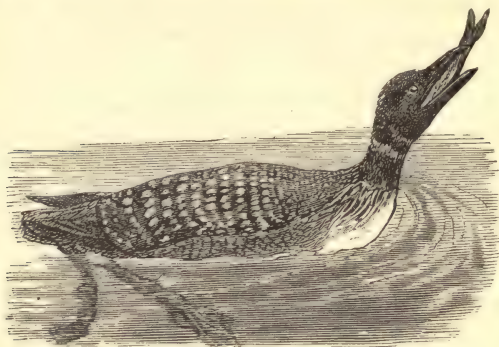


FIG. 141. — Loon (*Urinator imber*). North America.

ground.⁴² They always live in pairs, and the young are hatched helpless. In this group may be placed the pigeons, birds of prey, parrots, and the song birds.

The more important orders of birds are the following : —

1. *Pygopodes*, or divers.

These lowest of the feathered tribe have very short wings and tail, and the legs are placed so far back that they are obliged, when on land, to stand nearly bolt upright. They are better fitted for diving than for flight, or even swimming.

They belong to the high latitudes, living on fishes mainly, and are represented by the loons and grebes.

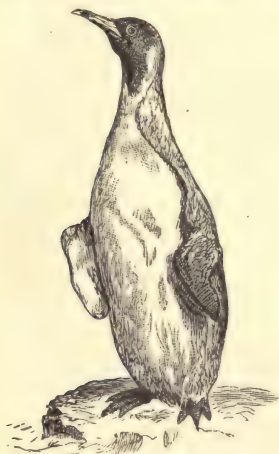


FIG. 142. — Penguin (*Aptenodytes penantii*). Falkland Islands.

2. *Impennes*, or penguins. These birds, found only in the southern hemisphere, have many of the structural features of those in the preceding order, but their wings are so rudimentary that flight is impossible (Fig. 142).

3. *Turbinares*, the albatrosses and petrels (largest and smallest of web-footed birds), having a hawklike, hooked bill and the nostrils opening through tubes. The wandering albatross inhabits the southern seas but sometimes comes as far north as Florida. It measures twelve to fourteen feet from tip to tip of its wings. Wilson's petrel (*Oceanites*), one of the smallest of the many species, is known to the sailor as "Mother Carey's chicken." The birds in this order are noted for their powers of flight.

4. *Steganopodes*, characterized by a long bill, generally hooked; wings rather long; and toes long, and all four joined together by broad webs. Throat generally naked, and furnished with a sac. The majority are large sea-birds, and feed on fishes, mollusks, and



FIG. 143. — Cormorant (*Phalacrocorax*). Copyright, 1901, by N. Y. Zoölogical Society.

insects. Examples are the cormorants, pelicans, gannets, and frigate bird (Fig. 143).

5. *Herodiones*. The herons, bitterns, storks, ibises, spoonbills and flamingoes are included in this order. (Fig. 144). They are readily distinguished by their long and bare legs. Generally, also, the toes, neck, and

bill are of proportionate length, and the tail short. They feed on small animals, and, with a few exceptions,



FIG. 144. — Heron (*Ardea*).

frequent the banks of rivers. In flying, their legs are stretched out behind, while in most other birds they are folded under the body.

6. *Anseres* have a heavy body, moderate wings, short tail, flattened bill, covered by a soft skin, with ridges along the edges. Diet more commonly vegetarian than animal. The majority inhabit fresh water—as the ducks, geese, and swans.

7. *Accipitres*, including the diurnal birds of prey. They have a strongly hooked beak with a waxy membrane (*cere*) at the base of the upper mandible, three toes in front and one behind. The toes are armed with long, strong, crooked talons; the legs are robust, the tarsus and toes usually without feathers being covered by scales; and the wings are of considerable size,

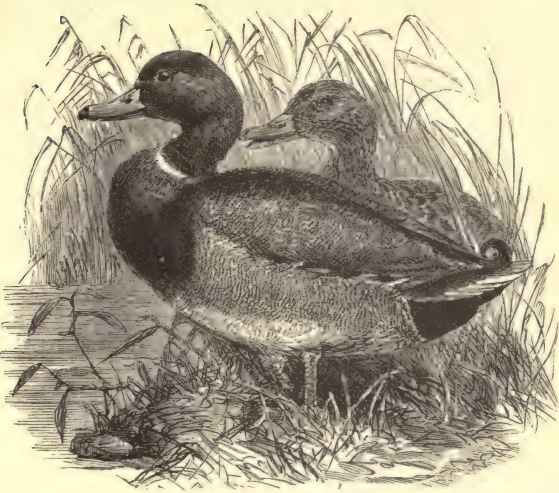


FIG. 145. — Wild duck (*Anas boschas*). North America.



FIG. 146. — Wild geese (*Branta canadensis*). United States. Copyright, 1901, by N.Y. Zoölogical Society.

adapted for rapid and powerful flight. The bill is stout and sharp, and usually toothed. The eyes are on the sides



FIG. 147. — Fishhawk (*Pandion haliaëtus carolinensis*). United States.

of the head, the wings pointed, and the plumage firm and close. All are carnivorous. The female is larger than the



FIG. 148. — Golden eagle (*Aquila chrysaëtos*). North America and Europe. Copyright, 1901, by N.Y. Zoological Society.

male, except the condor. Examples are the eagles, hawks, falcons, kites, and vultures.

8. *Gallinæ*. As a rule, this order, so valuable to man, is characterized by a short, arched bill; short and concave wings, unfitted for protracted flight; stout legs, of medium length; and four toes, the three in front being united by a

short web, and terminating in blunt claws. The legs are usually feathered to the heel, sometimes (as in grouse) to the toes. The feathers of the body are large and coarse. The males generally have gay plumage, and some appendage to the head. The nostrils are covered by a scale or valve. Their main food is grain. Such are the partridges, turkeys, pheasants, and poultry.



FIG. 149. — Prairie chicken (*Cupidonia cupido*).
Western prairies.

9. *Grallæ*. The rails and cranes are long-legged, marsh birds with four toes, of which the hinder one is usually small



FIG. 150. — Rail, or marsh hen (*Rallus elegans*).
United States.

and higher up than the front ones. The feet are adapted for wading, for standing upon floating vegetation, or walking over soft mud, having long spreading toes which aid in distributing the weight of the body over much surface. Cranes eat frogs, field mice, and snakes as well as vegetable food, while rails are fond of mollusks and worms.

10. *Gaviæ*, distinguished by their long, pointed wings, usually long tail, and by great powers of flight. They are all carnivorous. Such are the gulls and terns, which frequent the seacoast, lakes, and rivers; and the



FIG. 151. — Tern (*Sterna*).

auk which is found in northern seas. The great auk was flightless and became extinct as a result of unre-

stricted killing by fishermen and others who regularly visited the nesting grounds of this bird on the islands and along the coast of the North Atlantic for the purpose of collecting the eggs, and killing the birds for their feathers and oil.

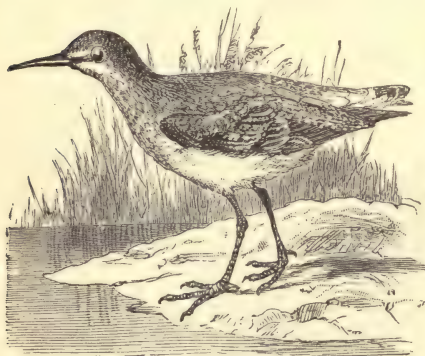


FIG. 152. — Sandpiper (*Tringa hypoleuca*). England.

The last living specimen of the great auk was seen in 1842.

11. *Limicolæ*, or shore birds, include the snipes, plovers, woodcock, sandpipers, phalaropes, stilts, avocets,

and jacanas. The toes are three or four in number, with the hind one when present elevated above the others, the legs are long, slender, and bare below. The phalaropes have webbed toes and can swim. They feed mainly upon worms and crustaceans which they dig out of the mud or from under stones with their long bills.

12. *Columbæ*, or pigeons and doves, have wings for prolonged flight, and slender legs, fitted rather for an arboreal life, with toes not united, and the hind toe on a level with the rest. Their



FIG. 153. — Ringdove (*Columba palumbus*).
England.

mode of drinking is peculiar, the head not being raised when the water is swallowed. The passenger pigeon, which was formerly very abundant in some sections of the country, seems to be approaching extinction. Wilson, the ornithologist, saw a flock in 1808 in Ken-



FIG. 154. — Foot of parrot and woodpecker.

tucky in which he estimated there were 2,230,272,000 individuals. At present the bird is seen only occa-

sionally. The extinct, flightless dodo (*Didus*), a native of the island of Mauritius, belonged in this order.

13. *Psittaci*, or parrots. These birds have a strong, arched upper



FIG. 155. — Barn owl (*Strix pratensis*). Both hemispheres. Copyright, 1901, by N. Y. Zoölogical Society.

bill, with a cere at the base, a fleshy, thick, and movable tongue, and paired toes. They have, usually, brilliant plumage. They live in trees and feed on fruits. Such are the parrots, paroquets, cockatoos, and macaws.



FIG. 156. — *Trogon elegans*. Central America.

14. *Striges*, or owls, have many of the characters of the *Accipitres*, but may be distinguished from them by having their large eyes directed forward and surrounded by radiating feathers, a feathered tarsus, and soft plumage (Fig. 155).

15. *Picariæ*. This heterogeneous group is sometimes subdivided into several orders since its members are too unlike, structurally, to be classed together.⁴⁸ The toes are usually paired, two in front and two behind.



FIG. 157. — Goatsucker (*Caprimulgus*).

As here given the order includes swifts, goatsuckers (Fig. 157), humming birds, cuckoos, kingfishers (Fig. 158), trogons (Fig. 156), toucans, hornbills, hoopoes, and woodpeckers. These birds are not musical, and only ordinary fliers. The most of them feed on insects or fruit. The majority make nests in the hollows of old trees; but the cuckoos often lay in the nests of other birds. In climbing, the woodpeckers are assisted by their stiff tail.



FIG. 158. — Kingfisher (*Ceryle*).



FIG. 159. — Head of a flycatcher (*Tyrannus*).

16. *Passeres*. This order is the most numerous and varied in the whole class. It comprehends all those



FIG. 160. — White-throated sparrow (*Zonotrichia albicollis*). United States.

tribes which live habitually among trees, excepting the rapacious and climbing birds, whose toes — three in



FIG. 161. — Redstart (*Setophaga ruticilla*). United States.

front, and one behind — are eminently fitted for perching only. The legs are slender, and seldom used for locomotion.

They are divisible into two sections: *a. Clamatores*, having the tarsus usually enveloped in a row of plates meeting behind in a groove, and the bill broad, and bent

down abruptly at the tip. Representatives are the tyrant flycatchers (Fig. 159). *b. Oscines*, or songsters,



FIG. 162. — White eyed vireo (*Vireo noveboracensis*). United States.

all of whom have a vocal apparatus, though not all sing. The anterior face of the tarsus is one continuous plate, or divided transversely into large scales; and the plates on the sides meet behind in a ridge. The toes, always three in front and one behind, are on the same level. The eggs are usually colored. Here belong the crows, jays, birds of paradise, blackbirds, orioles, larks,

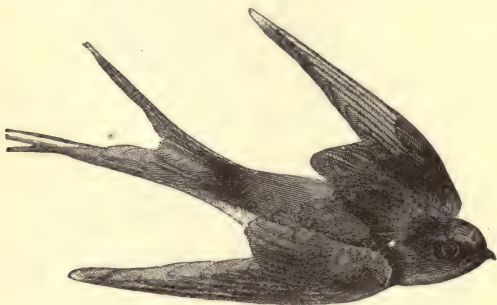


FIG. 163. — Swallow (*Hirundo*).

sparrows (Fig. 160), tanagers, finches, waxwings, swallows (Fig. 163), wrens, warblers (Figs. 161, 162), thrushes, etc.

CLASS VI. — Mammalia

Mammals are distinguished from all other vertebrates by any one of the following characters: they suckle their young; the thorax and abdomen are separated by a perfect diaphragm; the red corpuscles of the blood have no nucleus, and are therefore double concave (Fig. 259), and either a part or the whole of the body is hairy at some time in the life of the animal (Fig. 291, 301).⁴⁴

They are all warm-blooded vertebrates, breathing only by lungs, which are suspended freely in the thoracic cavity; the heart is four-chambered, and the circulation is double, as in birds (Fig. 273); the aorta is single, and bends over the left bronchial tube; the large veins are furnished with valves; the red corpuscles differ from those of all other vertebrates in having no nucleus and in being circular (except in the camel); the entrance to the windpipe is always guarded by an epiglottis; the cerebrum is more highly developed than in any other class, containing a greater amount of gray matter and (in the higher orders) more convolutions; the cerebellum has lateral lobes, a mammalian peculiarity, and there is a *corpus callosum* and a *pons varolii* (Fig. 335,

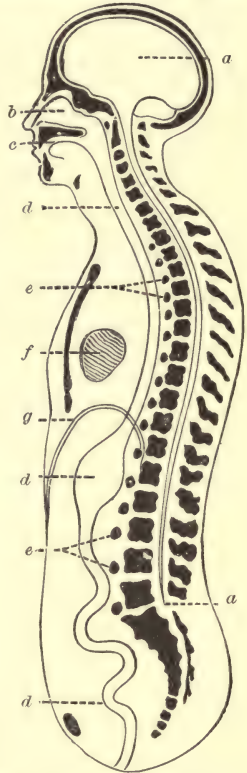


FIG. 164. — Longitudinal section of human body (theoretical): *a*, cerebro-spinal nervous system; *b*, cavity of nose; *c*, cavity of mouth; *d*, alimentary canal; *e*, chain of sympathetic ganglia; *f*, heart; *g*, diaphragm.

339, 342), the cranial bones are united by sutures, and they are fewer than in cold-blooded vertebrates; the skull has two occipital condyles, a feature shared by the amphibians; the lower jaw consists of two pieces only (often united), and articulates directly with the cranium; with four exceptions there are always seven cervical vertebræ:⁴⁵ the dorsal vertebræ, and therefore the ribs, vary from ten to twenty-four; the lumbar vertebræ number from two to nine; the sacral from three to nine, and the caudal from two to forty-six; the

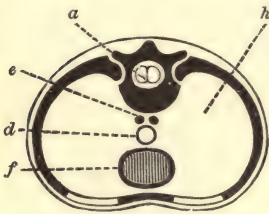


FIG. 165 — Transverse section of human body (theoretical): *a*, cerebro-spinal nervous axis contained in neural tube; *e*, chain of sympathetic ganglia; *d*, alimentary canal; *f*, heart; *h*, body cavity.

articulating surfaces of the vertebræ are generally flat; the fore limbs are never wanting, and the hind limbs only in a few aquatic forms; excepting the whales, each digit carries a nail, claw, or hoof; the teeth (always present, save in certain low tribes) are usually in two sets, a milk or deciduous set, and a permanent set, and are

planted in sockets; the mouth is closed by flexible lips; an external ear is rarely absent;⁴⁶ the eyes are always present though rudimentary in some burrowing animals; they are viviparous; and, finally, and perhaps above all, while in all other animals the embryo is developed from the nourishment laid up in the egg itself, in mammals it draws its support, almost from the beginning, directly from the parent, and, after birth, it is sustained for a time by the milk secreted by the mammary glands (Fig. 367). From the first, therefore, till it can care for itself, the young mammal is in vital connection with the parent.

About twenty-one hundred species are known, inhabiting the land, the water, and the air.

SUBCLASS I. — Prototheria

These mammals have but one outlet for the intestine, urinary and reproductive organs, as in birds. They are implantental, and the mammary glands are rudimentary. There is but one order.

1. *Monotremata*. This order includes two singular forms, the duck mole (*Ornithorhynchus*) and spiny ant-eater (*Echidna*), both confined to the Australian



FIG. 166. — *Ornithorhynchus*.

continent and New Guinea. The former has a covering of fur, a bill like that of a duck, and webbed feet. The latter is covered with spines, has a long, toothless snout, like the ant-eater's, and the feet are not webbed. Both burrow, and feed upon insects. The brain is smooth in the ornithorhynchus, and folded in the echidna. In both, the cerebral hemispheres are loosely united by transverse fibers, and do not cover the cerebellum and olfactory lobes.⁴⁷ Both lay eggs which resemble those of birds and from which the young are hatched.

SUBCLASS II. — Theria

In these mammals the mammary glands are typically developed and there is no cloaca.

There are two sections : —

SECTION A. — Metatheria

In this group are the marsupials, opossums, bandicoots, wombats, and kangaroos.

Marsupialia are distinguished by the fact that the young, always born premature, are transferred by the mother to a pouch on the abdomen, where they are attached to the nipples, and the milk is forced into



FIG. 167. — Virginia opossum (*Didelphys virginiana*).

their mouths by special muscles.⁴⁸ They have “marsupial bones” projecting from the pelvis, which may serve to support the pouch; though as the monotremes have the same bones, but no pouch, they doubtless have some other function. These bones are peculiar to animals having no placenta, namely, to monotremes and marsupials. The brains of marsupials resemble those of the monotremes, except that the cerebrum of

the kangaroo covers the olfactory lobes. All have the four kinds of teeth, and all are covered with fur, never with spines or scales. Except the opossums of America, all are restricted to Australia and adjacent islands. The marsupials are almost the only mammals of Australia, there being very few species of placental mammals. The marsupials have here developed into forms corresponding in their habits to the orders of placental mammals in the rest of the world. The kangaroos take the place of the large herbivores—the ungulates. The thylacinus and dasyurus are the marsupial carnivora. Other forms are squirrel-like in shape and habits, and still others are insectivorous.

SECTION B.—Eutheria

In these mammals the young are connected with the mother by means of a vascular structure, the placenta, by which they are nourished. They are born in a relatively perfect condition. There is no marsupial pouch. The following orders are included:—

1. *Edentata*.—This strange order contains very diverse forms, as the leaf-eating sloths and the insectivorous ant-eaters and armadillos of South America, and the pangolin and orycteropus of the Old World. The gigantic fossils, megatherium and glyptodon, belong to this group.

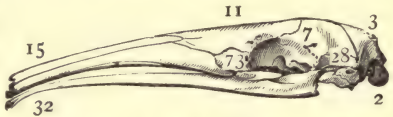


FIG. 168.—Skull of the great ant-eater (*Myrmecophaga jubata*): 15, nasal; 11, frontal; 7, parietal; 3, superoccipital; 2, occipital condyles; 28, tympanic; 73, lachrymal; 32, lower mandible. Teeth wanting.

The sloths and ant-eaters are covered with coarse hair; the armadillos and pangolins, with an armor of plates or scales (Fig. 298). The ant-eaters and pangolins are strictly edentate, or toothless; the rest have molars, wanting, however, enamel and roots. In general, it

may be said that the order includes all quadrupeds having separate, clawed toes and no incisors. The sloths are arboreal; the others burrow. The brain is generally smooth; but that of the ant-eater is convoluted, and has a large corpus callosum; but in all the cerebellum and part of the olfactory lobes are exposed.

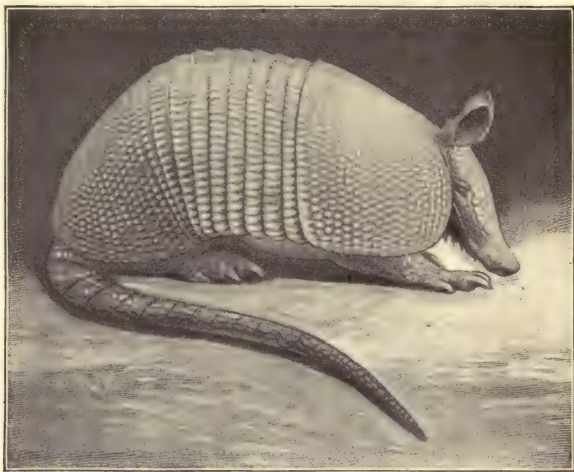


FIG. 169. — Armadillo (*Dasypus*). Copyright, 1901, by N.Y. Zoölogical Society.

2. *Cetacea*, or whales, have the form and life of fishes, yet they possess a higher organization than the preceding orders. They have a broad brain, with many and deep foldings; the foramen magnum of the skull is entirely posterior; the whole head is disproportionately large, and the jaws greatly prolonged. The body is covered with a thick, smooth skin, with a layer of fat ("blubber") underneath; there are no clavicles; the hind limbs are wanting, and the front pair changed to paddles (Fig. 171); the tail expands into a powerful, horizontal fin; neck and external ears are wanting; the eyes small, with only two lids; the nostrils (blowholes) — double in the whale,

single in the porpoise — are on the top of the head. All are carnivorous, and essentially marine, a few dolphins only being found in the great rivers. In the whalebone

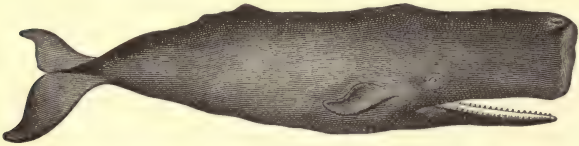


FIG. 170. — Outline of the sperm whale (*Physeter*). The blowhole is seen at the extreme tip of the head. In this region the spermaceti is found. Maximum length, eighty-five feet. South Atlantic.

whales, the teeth are absorbed, and disappear before birth, and their place is supplied by horny "baleen" plates (Fig. 228). "The whale feeds by putting this



FIG. 171. — Greenland whale (*Balæna mysticetus*). North Atlantic.

gigantic strainer into operation, as it swims through the shoals of minute mollusks, crustaceans, and fishes, which are constantly found at the surface of the sea. Open-

ing its capacious mouth, and allowing the sea water, with its multitudinous tenants, to fill the oral cavity, the whale shuts the lower jaw upon the baleen plates, and straining out the water through them, swallows the prey stranded upon its vast tongue." In the other cetaceans teeth are developed, especially in dolphins and porpoises; but the sperm whale has them only in the lower jaw, and the narwhal can show but a single tusk. In the toothed cetaceans the organ of smell is very rudimentary or even absent (dolphins).

3. *Sirenia* resemble the cetaceans in shape, but are closely allied to the hoofed animals in organization.



FIG. 172. — Troop of dolphins, with manatee in the distance.

They have the limbs of the whales, and are aquatic; but they are herbivorous, and frequent great rivers and estuaries. They have two sets of teeth, the cetaceans having but one. They have a narrow brain; bristles scantily covering the body; and nostrils placed on the

snout, which is large and fleshy. The living representatives are the manatee, of both sides of the tropical Atlantic Ocean, and the dugong of the East Indies (Fig. 270).

4. *Ungulata*, or hoofed quadrupeds. This large order, comprehending many animals most useful to man, is distinguished by four well-developed limbs, each toe being generally encased in a hoof (Fig. 300). The leg, therefore, has no prehensile power; it is only for support and locomotion. Clavicles are wanting; and the radius and ulna are so united as to prevent rotation

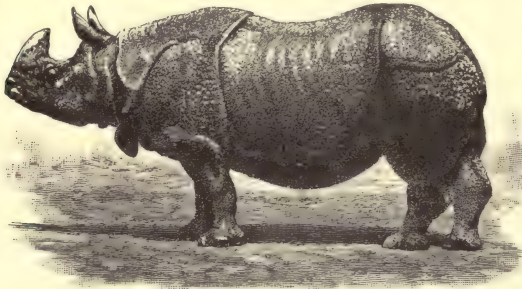


FIG. 173. — Indian rhinoceros (*R. indicus*).

(Figs. 314, 316). There are always two sets of teeth, *i.e.*, milk teeth are succeeded by a permanent set. The grinders have broad crowns (Figs. 234, 308). As a rule all are herbivorous. The brain is always convoluted, but the cerebellum is largely uncovered (Fig. 335).

Ungulates are divided into two groups: those in which the feet are always digitigrade, with never more than four functional digits, as the horse, ox, and rhinoceros; and those in which the feet may be plantigrade with four or five digits, as the cony (*Hyrax*), of Syria, and the elephant. The dental formula of the horse is —

$$i \frac{3-3}{3-3}, c \frac{1-1}{1-1}, pm \frac{3-3}{3-3}, m \frac{3-3}{3-3} = 40.$$

The canines are often wanting in the mare. The horse⁴⁹ walks on the third finger and toe. The metacarpals and metatarsals are greatly elongated, so that the wrist and heel are raised to the middle of the leg (Fig. 314). The rhinoceros and tapir⁵⁰ each have three toes. The first is distinguished by its very thick skin, the absence of canines, and one or two horns on the nose. The tapir has the four kinds of teeth, and a short proboscis.

The *Even-toed* Ungulates — hog, hippopotamus, and ruminants — have two or four toes. The hog and hippopotamus have the four kinds of teeth (Fig. 232); and, in the wild state, are vegetarian. The ruminants have two toes on each foot, enveloped in hoofs which face each other by a flat side, so that they appear to be a single hoof split or "cloven." Usually there are also two supplementary hoofs behind, but they do not ordinarily touch the ground. All chew the cud, and have a complicated stomach (Fig. 254). They have incisors in the lower jaw only, and these are apparently eight; but the two outer ones are canines.⁵¹ The molars are flat, typical grinders. The dental formula of the ox is —

$$i \frac{0-0}{3-3}, c \frac{0-0}{1-1}, pm \frac{3-3}{3-3}, m \frac{3-3}{3-3} = 32.$$

With few exceptions, as the camel, all ruminants have horns, which are always in pairs. Those of the deer are solid, bony, and deciduous; those of the giraffe and antelope are solid, horny, and permanent; in the goat, sheep, and ox, they are hollow, horny, and permanent.

The elephant, now nearly extinct, is characterized by two upper incisors in the form of tusks, mainly composed of dentine (ivory). In the extinct *dinotherium* the tusks projected from the lower jaw; and in the *mastodon*, from both jaws. Canines are wanting. The molars are few and large, with transverse ridges (elephant) or tubercles (*mastodon*). The cerebrum is large

and convoluted, but does not cover the cerebellum. The skull is enormous, the size arising in great measure from the development of air cavities between the inner and outer plates. The nose is prolonged into a flexible trunk, which is a strong and delicate organ of prehension. There are four massive limbs, each with five toes incased in broad, shallow hoofs, and also with a thick,



FIG. 174. — Stag, or red deer (*Cervus elaphus*). Europe. Copyright, 1901, by N.Y. Zoölogical Society.

tegumentary pad. The knee is below and free from the body, as in monkeys and men. Clavicles are wanting (Fig. 316). The body of the elephant is nearly naked; but the mammoth, an extinct species, had a covering of long woolly hair. Elephants live in large herds, and subsist on foliage and grass. There are but two living species: the Asiatic, with long head, concave forehead, small ears, and short tusks; and the African, with round head, convex forehead, large ears, and long tusks.⁵²

5. *Carnivora*, or beasts of prey, may be recognized by their four long, curved, acute, canine teeth, the gap be-



FIG. 175. — Raccoon (*Procyon lotor*). United States.



FIG. 176. — Wolf (*Lupus occidentalis*). United States.
Copyright, 1901, by N.Y. Zoölogical Society.



FIG. 177. — Ermine weasel (*Putorius noveboracensis*).
United States.

tween the incisors and canines in the upper jaw for the reception of the lower canine, and molars graduating from a tuberculate to a trenchant form, in proportion as the diet deviates from a miscellaneous kind to one strictly of flesh (Figs. 303, 307). The incisors, except in the pinnigrades, number six in each jaw. There are always two sets. The skull is comparatively small, the jaws are shorter and deeper than in ungulates, and there are numerous bony ridges on the inside and outside of the cranium — the high occipital crest being specially char-

acteristic. The cerebral hemispheres are joined by a large corpus callosum, but the cerebellum is never

completely covered (Fig. 339). Both pairs of limbs are well developed, the front being prehensile; but the clavicles are rudimentary. The humerus and femur are mainly inclosed in the body. The digits, never less than four, always have sharp and pointed claws.⁵³ The body is covered with abundant hair.

Carnivorēs may be divided according to the modifications of the limbs:

a. Pinnigrades, having short feet expanded into webbed paddles for swimming, the hinder ones being bound in with the skin of the tail. Such are the seals, walrus,



FIG. 178. — Red fox (*Vulpes pennsylvanicus*). United States. Copyright, 1901, by N. Y. Zoölogical Society.



FIG. 179. — Southern sea lion (*Otaria jubata*). Antarctic Ocean.

and eared seals, or sea lions. *b. Plantigrades*, in which the whole, or nearly the whole, of the hind foot forms a sole, and rests on the ground. The claws are not

retractile; the ears are small, and tail short. Bears, badgers, and raccoons are well-known examples. *c. Digitigrades* keep the heel raised above the ground, walking on the toes. The majority have long tails. Such are the weasels, otters, civets, hyenas, foxes, jackals, wolves, dogs, cats, panthers, leopards, tigers, and lions. The last five differ from all others in having retractile claws, and the radius rotating freely on the ulna. The cats have thirty teeth; the dogs, forty-two, or twelve more molars. In the former, the tongue is prickly; in the latter, smooth.

6. *Rodentia*, or gnawers, are characterized by two long, curved incisors in each jaw, enameled in front,

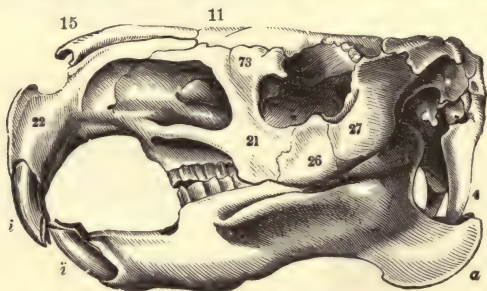


FIG. 180. — Skull of a rodent (*Capybara*): 22, premaxillary; 21, maxillary; 26, molar; 27, squamosal; 73, lachrymal; 15, nasal; 11, frontal; 4, occipital processes, unusually developed; 2, incisors; a, angle of lower jaw.

and perpetually growing; they are specially formed for nibbling. Separated from them by a wide space (for canines are wanting), are the flat molars, admirably fitted for grinding. The lower jaw has longitudinal condyles, which work freely backward and forward in longitudinal furrows. Nearly all have clavicles, and the toes are clawed. The cerebrum is nearly or quite smooth, and covers but a small part of the cerebellum. All are vegetarian.

More than one half of all known mammals are rodents.

They range from the equator to the poles, over every continent, over mountains and plains, deserts and woods.

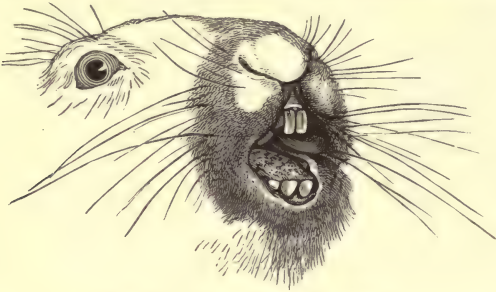


FIG. 181. — Incisor teeth of the hare.

The more important representatives are the porcupines, capybaras, guinea-pigs, hares, mice, rats, squirrels, and



FIG. 182. — Beaver (*Castor canadensis*). North America. Copyright, 1900, by A. Radcliffe Dugmore.

beavers. The capybara and beaver are the giants of the race.

7. *Insectivora* are diminutive, insect-eating animals, some, as the shrew, being the smallest of mammals.



FIG. 183. — Shrew mouse (*Sorex*).

They have small, smooth brains, which, as in the preceding orders, leave uncovered the cerebellum and olfactory lobes. The molar teeth bristle with sharp, pointed cusps, and are associated with canines and incisors.

They have a long muzzle, short legs, and clavicles. The feet are formed for walking or grasping, and are plantigrade, five-toed, and clawed. The shrew, hedgehog, and mole are examples.

8. *Cheiroptera*, or bats, repeat the chief characters of the Insectivores; but some (as the flying fox) are fruit-eaters, and have corresponding modifications of the

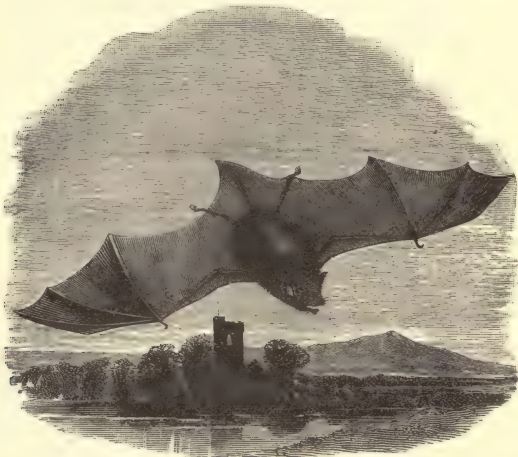


FIG. 184. — Bat (*Vespertilio*).

teeth. They are distinguished by their very long fore limbs, which are adapted for flight, the fingers being immensely lengthened, and united by a membranous web.

The toes, and one or two of the fingers, are armed with hooked nails. The clavicles are remarkably long, and the sternum is of great strength; but the whole skeleton is extremely light, though not filled with air, as in



FIG. 185. — Skeleton of a bat.

birds. The eyes are small, the ears large, and the sense of touch is very acute. The favorite attitude of a bat when at rest is that of suspension by the claws, with head downward. They are all nocturnal.

9. *Primates*, the head of the kingdom, are characterized by the possession of two hands and two feet. The thigh is free from the body, and all the digits are furnished with nails, the first on the foot enlarged to a "great toe." Throughout the order, the hand is eminently or wholly prehensile, and the foot, however prehensile it may be, is always a locomotor organ (Fig. 192).⁵⁴ The clavicles are perfect (Fig. 317). The eyes are situated in a complete bony cavity, and look forward. There are two sets of teeth, all enameled; and the incisors number four in each jaw (Fig. 233). They include the lemurs, monkeys and apes, and man.

The lemurs are covered with soft fur, have usually a long tail, pointed ears, foxlike muzzle, and curved nostrils. They walk on all fours, and the thumb and great toe are generally opposable to the digits. The

second toe has a long, pointed claw instead of a nail. The cerebrum is relatively small, and flattened, and

does not cover the cerebellum and olfactory lobes.⁵⁵ They are found mainly in Madagascar.



FIG. 186. — Lemur (*L. ruber*). Madagascar.
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The monkeys of tropical America have, generally, a long, prehensile tail; the nostrils are placed far apart, so that the nose is wide and flat;

the thumbs and great toes are fitted for grasping, but are



FIG. 187. — White-throated sapajou (*Cebus hypoleucus*). Central America.

not opposable to the other digits; and they have four molars more than the apes or man — that is, thirty-six

teeth in all. In the apes of the Old World the tail is never prehensile, and is sometimes wanting; the nostrils are

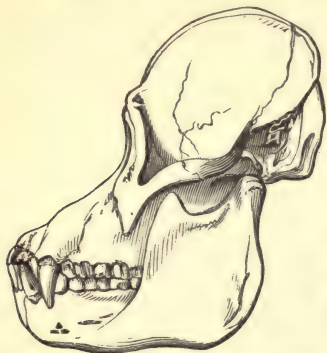


FIG. 188. — Skull of orang-outang (*Simia satyrus*).

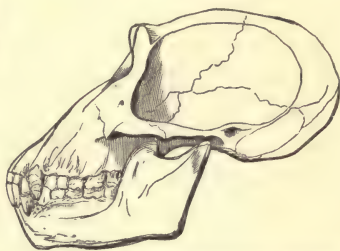


FIG. 189. — Skull of chimpanzee (*Anthropopithecus troglodytes*).

close together; both thumbs and great toes are opposable; and the teeth, though numbering the same as man's,



FIG. 190. — Female orang-outang (from photograph). Borneo.

are uneven (the incisors being prominent, and the canines large), and the series is interrupted by a gap on one side

or other of the canines. Their average size is much greater than that of the monkeys, and they are not so strictly arboreal. In both monkeys and apes the cerebrum covers the cerebellum (Fig. 340).⁵⁶ While in the monkeys the skull is rounded and smooth, that of the apes, especially those coming nearest to man — the anthropoid, or long-armed, apes, as gorilla, chimpanzee, orang, and gibbon — is characterized by strong crests. Monkeys take a horizontal position; but the apes assume a semierect attitude, the legs being shorter than the arms. In all the primates but man, the body is clothed with hair, which is generally longest on the back. Several monkeys and apes have a beard, as the howler and orang.

The orang is the least human of all the anthropoid

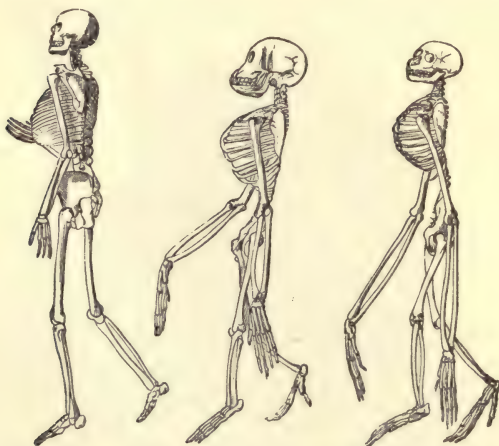


FIG. 191. — Skeletons of man, chimpanzee, and orang.

apes as regards the skeleton, but comes nearest to man in the form of the brain. The chimpanzee approaches man more closely in the character of its cranium and teeth, and the proportional length of the arms. The

gorilla is most manlike in bulk (sometimes reaching the height of five feet six inches), in the proportions of the leg to the body and of the foot to the hand, in the size of the heel, the form of the pelvis and shoulder blade, and volume of brain.⁵⁷



FIG. 192 — Gorilla.

Man differs from the apes in being an erect biped. In him, the vertebrate type, which began in the horizontal fish, finally became vertical. No other animal habitually stands erect; in no other are the fore limbs used exclusively for prehensile purposes, and the hind pair solely for locomotion.

His limbs are naturally parallel to the axis of his body, not perpendicular. They have a near equality of length, but the arms are always somewhat shorter than the legs. In all the great apes the arms reach below the knee, and the legs of the chimpanzee and gorilla are relatively shorter than man's.

Only man has a finished hand, most perfect as an

organ of touch, and most versatile. Both hand and foot are relatively shorter than in the apes. The foot



FIG. 193. — Foot (*a*) and hand (*b*) of the gorilla.

is plantigrade; the leg bears vertically upon it; the heel and great toe are longer than in other primates; and the great toe is not opposable, but is used only as a fulcrum in locomotion. The gorilla has both an



FIG. 194. — Australian savage.

inferior hand and inferior foot. The hand is clumsier, and with a shorter thumb than man's; and the

foot is prehensile, and is not applied flat to the ground.⁵⁸

The scapular and pelvic bones are extremely broad, and the neck of the femur remarkably long. Man is also singular in the double curve of the spine: the baboon comes nearest to man in this respect.

The human skull has a smooth, rounded outline, elevated in front, and devoid of crests. The cranium greatly predominates over the face, being four to one;⁵⁹ and no other animal (except the siamang gibbon) has a chin.

Man stands alone in the peculiarity of his dentition:



FIG. 195. — Skull of European.

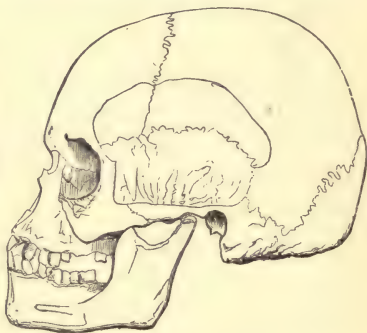


FIG. 196. — Skull of negro.

his teeth are vertical, of nearly uniform height, and close together. In every other animal the incisors and canines are more or less inclined, the canines project, and there are vacant spaces.⁶⁰

Man has a longer lobule to his ear than any ape, and no muzzle. The bridge of his nose is decidedly convex; in the apes generally it is flat.

Man has been called the only naked terrestrial mammal. His hair is most abundant on the scalp; never on the back, as in the apes.

Man has a more pliable constitution than the apes, as

shown by his world-wide distribution. The animals nearest him soon perish when removed from their native places.

Though man is excelled by some animals in the acuteness of some senses, there is no other animal in which all the senses are capable of equal development. He alone has the power of expressing his thoughts by articulate speech, and the power of forming abstract ideas.

Man differs from the apes in the absolute size of the brain, and in the greater complexity and less symmetrical disposition of its convolutions. The cerebrum is larger in proportion to the cerebellum (being as $8\frac{1}{2}$ to 1), and the former not only covers the latter, but projects beyond it. The brain of the gorilla scarcely amounts to one third in volume or one half in weight of that of man. Yet, so far as cerebral structure goes, man differs less from the apes than they do from the monkeys and lemurs.

The view held by evolutionists that man and the man-like apes are descendants of a common ancestor is based upon arguments drawn from structural and physiological features. In his anatomy man resembles apes more closely than any other group of animals. He differs from them mainly in having a much larger brain. In his skeletal, muscular, nervous, and other systems he possesses about seventy-five vestigial structures, *i.e.*, anatomical parts which are more perfectly developed and more useful in apes and lower animals. Physiologically, man resembles the apes in having a similar bodily life, in performing many actions in the same manner, in being subject to the same diseases, in making similar gestures, facial expressions, etc. The great gulf between man and the brute is not physical, but psychical.⁶¹

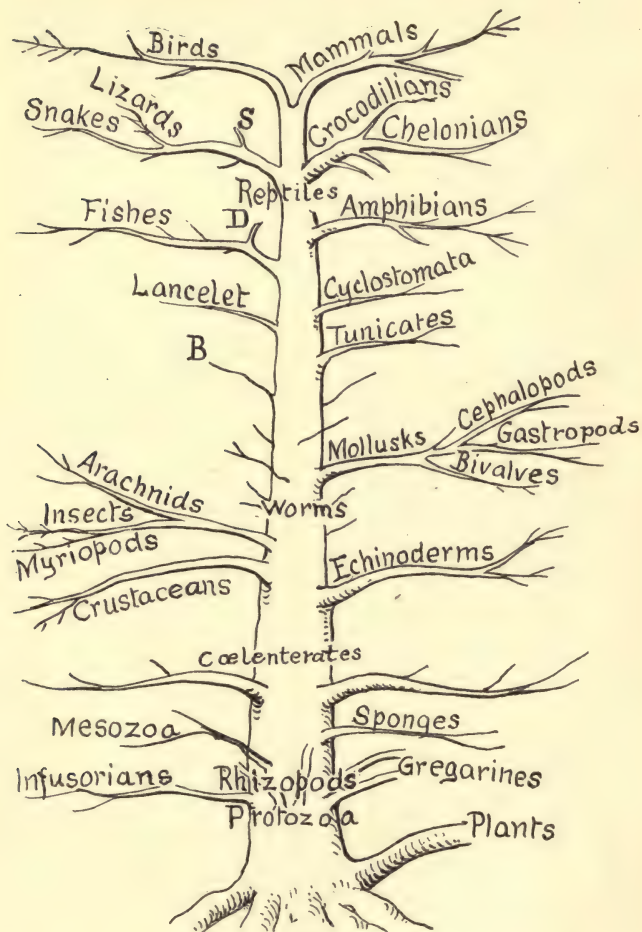


FIG. 197. — Diagrammatic expression of classification in a genealogical tree. B indicates possible position of Balanoglossus, D of Dipnoi, S of Sphenodon or Hatteria.

CHAPTER III

SYSTEMATIC ARRANGEMENT OF REPRESENTATIVE FORMS

SERIES I., PROTOZOA. — Animals without cellular tissues or true eggs.

Branch I. PROTOZOA. — With same characteristics.

CLASS I. Rhizopoda. — Having the power of throwing out pseudopodia.

Order 1. LOBOSA. — With short, blunt pseudopodia: *Amœba*.

Order 2. FORAMINIFERA. — With fine, anastomosing pseudopodia and calcareous shell; { single: *Lagena*.
compound: *Nummulites*.

Order 3. HELIOZOA. — With fine, stiff, radiating pseudopodia: *Actinophrys*.

Order 4. RADIOLARIA. — With siliceous shell: *Podocorytis*.

CLASS II. Mycetozoa. — Terrestrial Protozoa, forming large amoeboid plasmodia and having plantlike spore-stage: *Trichia*.

CLASS III. Mastigophora. — Having one flagellum or more, as the organ of motion: *Euglena*.

CLASS IV. Sporozoa. — Consisting of one cell, and parasitic: *Gregarina*.

CLASS V. Infusoria. — Having cuticle, mouth, and cilia or tentacles.

Order 1. CILIATA. — Bearing vibratile cilia; { fixed: *Vorticella*.

{ free: *Paramecium*.

Order 2. TENTACULIFERA. — With suctorial tentacles: *Actineta*.

SERIES II., METAZOA. — Animals with cellular tissues, true eggs, and blastoderm.

Branch II. PORIFERA. — Metazoa, with numerous incurrent openings, one or few excurrent orifices, generally a skeleton, independent cells.

CLASS I. **Porifera**. — Same characteristics.*Subclass 1. CALCAREA*. — Skeleton of calcareous spicules: *Grantia*.*Subclass 2. NON-CALCAREA*. — Skeleton, if present, of spongin fibers (*Euspongia*), or of siliceous spicules (*Euplectella*).**Branch III. Cœlenterata**. — Radiate Metazoa, body consisting of two cell layers, with distinct digestive cavity, tentacles, and netting thread cells.CLASS I. **Hydrozoa**. — Single digestive cavity, with which the mouth communicates freely.*Order 1. LEPTOLINÆ*. — Fixed by adherent disk; { single: *Hydra*.
compound: *Eucopa*.*Order 2. HYDROCORALLINA*. — With a skeleton of line, forming a coral: *Millepora*.*Order 3. SIPHONOPHORA*. — Free and oceanic, swimming by crested air sac: *Physalia*.CLASS II. **Scyphozoa**. — Having gastric tentacles.*Order 1. STAUROMEDUSÆ*. — Cup-shaped, with marginal tufts of tentacles, and eight or more radiating canals; attached; single: *Lucernaria*.*Order 2. DISCOMEDUSÆ*. — Free and oceanic; disk-shaped, with marginal fringe of tentacles and "veil"; four canals; single: *Aurelia*.CLASS III. **Actinozoa**. — Double digestive cavity, with radiating septa.*Order 1. ACTINIARIA*. — Parts in some multiple of five or six; soft-bodied; single; slightly locomotive: *Actinia*.*Order 2. MADREPORARIA*. — Parts in some multiple of five or six; composite; fixed; secreting { sclerodermic, rough, calcareous coral: *Madrepora*.
sclerobasic, smooth coral: *Astræa*.*Order 3. ALCVONACEA*. — Eight parts; composite; fixed; { soft-bodied: *Alcyonium*.
secreting furrowed sclerobasic coral: *Corallium*.*Order 4. GORGONACEA*. — Tree-like, spicules present in mesogloea: *Gorgonia*.*Order 5. PENNATULACEA*. — Elongated colony with horny or calcareous axis: *Pennatula*.CLASS IV. **Ctenophora**. — Soft-bodied; transparent; free, moving by eight rows of tiny paddles; two tentacles; digestive cavity with anal outlet: *Pleurobrachia*.

Branch IV. PLATYHELMINTHES. — Body generally flattened, no true metameric segmentation, no body cavity nor blood-vascular system.

CLASS I. **Turbellaria.** — Nonparasitic, with ciliated epidermis; digestive cavity present: *Planaria*.

CLASS II. **Cestoda.** — Parasitic within the host; without cilia or digestive cavity: *Tænia*.

Branch V. NEMATHELMINTHES. — Body cylindrical, pointed at each end, cuticle tough, body cavity present.

CLASS I. **Nematoda.** — Characters of the branch: *Trichina*.

Branch VI. TROCHELMINTHES. — Microscopic but multicellular, with body cavity, digestive and nervous systems, body bearing cilia in rings or scattered over the surface.

CLASS I. **Rotifera.** — Cilia on a retractile disk at anterior end: *Brachionus*.

Branch VII. MOLLUSCOIDA. — Having a lophophore or tentacle bearing ridge at anterior end of body.

CLASS I. **Polyzoa.** — Forming colonies, minute, fixed: *Flustra*.

CLASS II. **Brachiopoda.** — Body inclosed in two-valved shell; no gills; two ciliated arms; fixed; marine: *Terebratula*.

Branch VIII. ECHINODERMATA. — Radiate Metazoa, with distinct alimentary canal and well-developed nervous system; body walls secreting calcareous plates; parts in multiple of five.

CLASS I. **Astroidea.** — Body star-shaped; free; mouth underneath; moving by suckers under the hollow lobes of the body: *Asterias*.

CLASS II. **Ophiuroidea.** — Body star-shaped; free; mouth underneath; moving by long slender arms: *Ophiura*.

CLASS III. **Echinoidea**. — Body inclosed in a spinous shell; free, moving by suckers; mouth { spherical: *Arbacia*,
underneath, with five teeth; flat: *Chyaster*.

CLASS IV. **Holothuroidea**. — Body cylindrical and soft; free, moving by suckers; mouth in front, surrounded by tentacles: *Pentacta*.

CLASS V. **Crinoidea**. — Body cup-shaped; mouth uppermost: *Pentacrinus*.

Branch IX. ANNULATA. — Soft body generally divided externally into a number of rings; no jointed appendages.

CLASS I. **Chætopoda**. — Body round, segments numerous, similar, and { bristles numerous: *Nereis*,
bearing horny bristles; bristles few on each segment: *Lumbricus*.

CLASS II. **Hirudinea**. — Body flat, with suckers at ends: *Hirudo*.

Branch X. ARTHROPODA. — Metazoa, usually with definite number of segments and jointed appendages.

§ 1. *Water-breathing*.

CLASS I. **Crustacea**. — Having gills and more than eight jointed legs; four antennæ.

Order 1. PHYLLOPODA. — Very small; body segmented and bearing cephalic shield: *Daphnia*.

Order 2. OSTRACODA. — Minute; unsegmented body inclosed in bivalve shell: *Cypris*.

Order 3. COPEPODA. — Small; body segmented and without dorsal shell: *Cyclops*.

Order 4. CIRRIPEDA. — Fixed; shelly covering; feathery "arms": *Balanus*.

Order 5. DECAPODA. — Shell of mingled lime and chitin; ten-footed; large: *Cambarus*.

Order 6. ARTHROSTRACA. — Thorax consisting usually of only six or seven segments; eyes sessile; small: *Oniscus*.

§ 2. *Air-breathing*.

CLASS II. **Onychophora**. — Body soft, cylindrical, unsegmented; legs soft, unjointed: *Peripatus*.

Branch ARTHROPODA—Continued.

§ 2. Air-breathing—Continued.

CLASS III. **Myriapoda**.—Segments similar; wormlike; chitinous skin; tracheæ; two antennæ; head.

Order 1. CHILOPODA.—Flattened; two legs to each joint: *Scolopendra*.

Order 2. DIPLOPODA.—Cylindrical; four legs to each joint: *Fulus*.

CLASS IV. **Insecta**.—Head, thorax, and abdomen distinct; chitinous crust; six thoracic legs; winged; two antennæ; tracheæ.

Order 1. ORTHOPTERA.—Four wings, front pair slightly thickened, narrow and overlapping, hind pair transparent, broad, and folded; biters: *Gryllus*.

Order 2. NEUROPTERA.—Slender abdomen; four equal, large, transparent wings; biters: *Libellula*.

wingless: *Cimex*.

Order 3. HEMIPTERA.—Suctorial; legs slender; { four wings; { transparent: *Cicada*.

forewings opaque at base: *Anasa*.

Order 4. DIPTERA.—Two transparent wings; slender legs; suctorial: *Musca*.

antennæ feathery: *Telea*.

antennæ spindle-shaped:

Sphinx.

antennæ knobbed: *Papilio*.

Order 5. LEPIDOPTERA.—Four large, scaly wings; legs not locomotive; spiral proboscis for suction;

Order 6. COLEOPTERA.—Four wings, front pair horny, uniting by straight edge; biters: *Harpalus*.

Order 7. HYMENOPTERA.—Four transparent wings; mouth fitted for both biting and suction: *Apis*.

CLASS V. **Arachnida**.—Eight thoracic legs; cephalothorax.

Order 1. SCORPIONIDA.—Long, jointed abdomen; pulmonary sacs: *Scorpio*.

Order 2. PHALANGIDA.—Body short and thick; unsegmented; legs long: *Phalangium*.

Order 3. ARANEIDA.—Soft, short, unjointed abdomen; spinnerets; pulmonary sacs: *Epeira*.

Order 4. ACARIDA.—Minute; no marked articulations; tracheal respiration; suctorial: *Ixodes*.

Order 5. XIPHOSURA.—Body covered by broad carapace; long spinelike tail; marine: *Limulus*.

Branch XI. MOLLUSCA. — Soft-bodied, unjointed Metazoa, with muscular skin ("mantle"), generally protected by a calcareous shell; two- or three-chambered heart; three main pairs of nerve ganglia.

§ 1. *No distinct head-region.*

{ two unequal muscular impressions: *Mytilus*.

CLASS I. **Pelecypoda.** — With unequal bivalve shell;
two pairs of gills;

{ one muscular impression: *Ostrea*.
{ two equal muscular impressions { no pallial sinus: *Unio*.
pallial sinus: *Venus*.

CLASS II. **Amphineura.** — Shell consisting of eight pieces: *Chiton*.

§ 2. *With distinct head-region.*

CLASS III. **Gastropoda.** — Generally with univalve, unchambered shell; two-chambered heart; three nervous ganglia; two tentacles.

Order 1. **ASPIDOBANCHIA.** — Gills plumelike; two auricles in heart; crawling by ventral foot: *Patella*.

Order 2. **PECTINIBANCHIA.** — Gill attached to wall of mantle, heart with single auricle; crawling: *Buccinum*.

Order 3. **OPISTHOBANCHIA.** — Heart with one auricle; mantle cavity with wide opening: { oceanic; swimming: *Hyalaea*.
naked; gills at posterior end of body: *Doris*.

Order 4. **PULMONATA.** — Air breathing; { naked: *Limax*.

{ with shell; { terrestrial: *Helix*.
fresh-water: *Limnaea*.

CLASS IV. **Cephalopoda.** — Symmetrical body; with arms around the mouth; walk and swim; marine; three-chambered heart.

Order 1. **DIBRANCHIATA.** — Two gills; naked; ink bag; { eight arms: *Octopus*.
ten arms: *Sepia*.

Order 2. **TETRABRANCHIATA.** — Having four gills, many tentacles, and an external, chambered shell: *Nautilus*.

Branch XII. CHORDATA. — Internal skeleton; notochord or backbone; nervous chord dorsal and separated from body cavity; circulation complete; limbs not more than four.

Subbranch 1. ADELOCHORDA. — Characters of class.

CLASS I. Adelochorda. — Wormlike; soft-bodied; notochord rudimentary; surface ciliated; gill slits present: *Balanoglossus*.

Subbranch 2. UROCHORDA. — Characters of class.

CLASS II. Urochorda. — Notochord temporary; body usually covered with a sac containing cellulose: *Ascidia*.

Subbranch 3. VERTEBRATA. — Notochord persistent or replaced by backbone.

Division A. Acrania. — No skull present.

CLASS III. Pharyngobranchii. — No limbs nor heart; blood corpuscles white; numerous ciliated gill slits: *Amphioxus*.

Division B. Craniata. — Skull present.

PROVINCE I. Ichthyopsida. — No amnion or allantois; epidermis thin or none; gills at some time during life: cold blood.

CLASS I. Cyclostomata. — Body naked; limbless; skeleton cartilaginous; mouth circular; gills in pouches: *Petromyzon*.

CLASS II. Pisces. — Permanent gills; median fins with fin rays; fins for limbs; heart with two cavities.

Subclass 1. ELASMOBRANCHII. — Shagreen skin; cartilaginous skeleton; tail heterocercal; gills fixed and uncovered: *Squalus*.

Subclass 2. TELEOSTOMI. — Having scales, fins, and bony skeleton; tail homocercal; $\left\{ \begin{array}{l} \text{soft-finned: } \textit{Salmo.} \\ \text{spiny-finned: } \textit{Percu.} \end{array} \right.$

Subclass 3. DIPNOI. — No vertebral centra; filiform fins; heart with three cavities: *Lepidosiren*.

Branch CHORDATA — Continued.

PROVINCE II. Sauropsida — Continued.

CLASS V. Aves. — Feathered; four limbs, hind pair for progression on land or water, front for flight; no teeth; three eyelids; one occipital condyle; heart with four cavities; lungs.

Division A. Ratitæ.

Order 1. CURSORES. — No keel on breastbone; rudimentary wings; stout legs: *Struthio*.

Division B. Carinatae. — Keel on breastbone; functional wings.

Order 1. PYGODES. — Feet far back; short wings: *Colymbus*.

Order 2. IMPENNES. — Wings rudimentary: *Alca*.

Order 3. TURBINARES. — Nostrils opening through tubes: *Diomedea*.

Order 4. STEGANOPODES. — All four toes joined by a web: *Phalacrocorax*.

Order 5. HERODIONES. — Legs and neck long; knee free from body: *Ardea*.

Order 6. ANSERES. — Heavy body; flattened bill; webbed feet: *Anas*.

Order 7. ACCIPITRES. — Hooked beak and talons; three toes in front and one behind; diurnal: *Aquila*.

Order 8. GALLINÆ. — Legs and wings short and stout; three front toes united by short web: *Gallus*.

Order 9. GRALLÆ. — Legs long; hind toe higher up than others: *Rallus*.

Order 10. GAVIÆ. — Long pointed wings; long tail; front toes webbed: *Sterna*.

Order 11. LIMICOLÆ. — Legs and bill usually long and slender; nostrils opening through slits; wings long and pointed: *Tringa*.

Order 12. COLUMBÆ. — Toes on same level; bill slender; nostrils opening through soft skin: *Columba*.

Order 13. PSITTACI. — Beak arched; tongue fleshy; toes paired; cere present: *Psittacus*.

Order 14. STRIGES. — Eyes directed forward; tarsus feathered; plumage soft: *Strix*.

Order 15. PICARIÆ. — Toes usually paired: *Picus*, *Ceryle*.

Order 16. PASSERES. — Legs short and slender; three toes in front, one behind: *Merula*.

PROVINCE III. **Mammalia.**

CLASS VI. **Mammalia.** — Suckle their young; red corpuscles double concave; heart with four cavities; lungs; diaphragm; body hairy; two occipital condyles.

SUBCLASS I. — *Prototheria*; *Cloacal Mammalia*.

Order 1. **MONOTREMATA.** — Duck-billed; webbed feet: *Ornithorhynchus*.

SUBCLASS II. — *Theria*.

Pouched Mammalia.

Order 1. **MARSUPIALIA.** — With pouch for immature young: *Didelphys*.

Placental Mammalia.

Order 1. **EDENTATA.** — { Toothless: *Myrmecophaga*.
Incisors wanting: *Bradyphus*.

Order 2. **CETACEA.** — Hind limbs wanting, front pair for swimming; nostrils on top of the head; carnivorous; { teeth wanting: *Balæna*.
teeth in lower jaw: *Physeter*.
teeth in both jaws: *Delphinus*.

Order 3. **SIRENIA.** — Herbivorous cetaceans; nostrils at the end of the snout; molars in both jaws: *Manatus*.

Order 4. **UNGULATA.** — Vegetarian; large, flat molars; { with tusks and proboscis: *Elephas*.
even-toed: *Bos*.
hoofs; { odd-toed: *Equus*.

Order 5. **CARNIVORA.** — Flesh eaters; claws; canines well developed; molars trenchant; { pinnigrade: *Phoca*.
plantigrade: *Ursus*.
digitigrade: *Felis*.

Order 6. **RODENTIA.** — Canines wanting; incisors highly developed: *Mus*.

Order 7. **INSECTIVORA.** — Molars with sharp points: *Scalops*.

Order 8. **CHEIROPTERA.** — Fore limbs webbed for flight: *Vespertilio*.

Order 9. **PRIMATES.** — { Arboreal; small; clawed; kidney-shaped nostrils; eyes and ears large: *Lemur*.
Four incisors in each jaw; great toe { teeth uneven; { nostrils apart: *Cebus*.
with flat nail; { nostrils close: *Simia*.
teeth even; erect: *Homo*.

PART II

COMPARATIVE ZOÖLOGY

CHAPTER IV

MINERALS AND ORGANIZED BODIES DISTINGUISHED

Nature may be separated into two great kingdoms,—that of mere dead matter, and that of matter under the influence of life.⁶² These differ in the following points:—

(1) **Composition.**—While most of the chemical elements are found in different living beings, by far the greater part of their substance is composed of three or four,—carbon, oxygen, and hydrogen; or these three with the addition of nitrogen. Next to these elements, sulphur and phosphorus are most widely distributed, though always found in very small quantities. The organic compounds belong to the carbon series, and contain three, four, or five elements. The former class, comprising starch, sugar, fat, etc., are relatively stable. The latter, possessing the three elements named, with nitrogen and sulphur or phosphorus, are very complex, containing a very large number of atoms to the molecule, and are usually unstable. Here belong albumen, myosin, chondrin, etc., the constituents of the living tissues. The formula for albumen is said to be $C_{72}H_{112}N_{18}SO_{22}$, or some multiple of this formula. These compounds also contain more or less water, and usually exist in a jelly-like condition, neither solid nor fluid. All organic compounds are formed through the chemical activities of *protoplasm*, which is the only *living* substance. Inorganic matter may, under its influence, be changed to organic, and *vice versa*; dead matter which enters the body of organized beings in the form of nutriment is

changed into living substance, which, after serving its purpose, passes again as waste to the inorganic world.

(2) **Structure.**—Minerals are homogeneous, while organized bodies are usually heterogeneous, *i.e.*, composed of different parts, called tissues and organs, having peculiar uses and definite relations to one another. The tissues and organs, again, are heterogeneous, consisting mainly of microscopic *cells*, structures developed only by vital action. All the parts of an organism are mutually dependent, and reciprocally means and ends, while each part of a mineral exists for itself. The smallest fragment of marble is as much marble as a mountain mass; but the fragment of a plant or animal is not an individual.

(3) **Shape and Size.**—Living bodies gradually acquire determinate dimensions; so do minerals in their perfect or crystal condition. But uncrystallized, inorganic bodies have an indefinite bulk. Most minerals are amorphous; crystals have regular forms, bounded, as a rule, by plane surfaces and straight lines; plants and animals are circumscribed by curved surfaces, and rarely assume accurate geometrical forms.⁶³

(4) **Phenomena.**—Minerals remain internally at rest, and increase by external additions, if they grow at all. Living beings are constantly changing the matter of which they are composed, and grow by taking new matter into themselves and placing it among the particles already present. Organized bodies, moreover, pass through a cycle of changes, — growth, development, reproduction, and death. These phenomena are characteristic of living as opposed to inorganic bodies. All living bodies grow from within, constantly give up old matter and replace it by new, reproduce their kind, and die; and no inorganic body shows any of these phenomena.

CHAPTER V *

PLANTS AND ANIMALS DISTINGUISHED

IT may seem an easy matter to draw a line between plants and animals. Who cannot tell a cow from a cabbage? Who would confound a coral with a mushroom? Yet it is impossible to assign any absolute, distinctive character which will divide the one form of life from the other. The difficulty of defining an animal increases with our knowledge of its nature. Linnæus defined it in three words;† a century later, Owen declared that a definition of plants which would exclude all animals, or of animals which would not let in a single plant, was impossible. Each different character used in drawing the boundary will bisect the debatable ground in a different latitude of the organic world. Between the higher animals and higher plants the difference is apparent; but when we reflect how many characters the two have in common, and especially when we descend to the lower and minuter forms, we discover that the two "kingdoms" touch, and even dissolve into, each other. This border land has been as hotly contested among naturalists as many a disputed frontier between adjacent nations. Its inhabitants have been taken and retaken several times by botanists and zoölogists; for they have characters that lead on the one side to plants, and on the other to animals. To solve the difficulty, some eminent naturalists, as Hæckel and

* See Appendix.

† "Minerals grow; plants grow and live; animals grow, live, and feel."

Owen, propose a fourth "kingdom," that of the *Protista*, to receive those living beings which are organic, but not distinctly vegetable or animal. But a greater difficulty arises in attempting to fix its precise limits.

The drift of modern research points to this: that there are but two kingdoms of nature, the mineral and the organized, and these closely linked together; that the latter must be taken as one whole, from which two great branches rise and diverge. "There is at bottom but one life, which is the whole life of some creatures and the common basis of the life of all; a life of simplest moving and feeling, of feeding and breathing, of producing its kind and lasting its day: a life which, so far as we at present know, has no need of such parts as we call organs. Upon this general foundation are built up the manifold special characters of animal and vegetable existence; but the tendency, the endeavor, so to speak, of the plant is one, of the animal is another, and the unlikeness between them widens the higher the building is carried up. As we pass along the series of either [branch] from low to high, the plant becomes more vegetative, the animal more animal." ⁶⁴

Defining animals and plants by their prominent characteristics, we may say that a living being which has cell walls of cellulose, and by deoxidation and synthesis of its simple food stuffs produces the complicated organic substances, is a plant; while a living being which has albuminous tissues, and by oxidation and analysis reduces its complicated food stuffs to a simpler form, is an animal. But both definitions are defective, including too many forms, and excluding forms that properly belong to the respective kingdoms. No definition is possible which shall include all animals and exclude all plants, or *vice versa*.

(1) **Origin.** — Both branches of the tree of life start alike: the lowest of plants and animals consist of a single cell. In fact, the cycle of life in all living beings begins in a small, round particle of matter, a cell—in the higher plants called an ovule, in the higher animals an ovum. This cell consists mainly of a semifluid substance called protoplasm. In the very simplest forms the protoplasm is not inclosed by a membrane or cell wall. In most plants the cell wall is present, and consists of cellulose, a substance akin to starch; in animals, with few exceptions, the wall is a pellicle of firmer protoplasm, *i.e.*, albuminous.

(2) **Composition.** — Modern research has broken down the partition between plants and animals, so far as chemical nature is concerned. The vegetable fabric and secretions may be ternary or binary compounds; but the essential living parts of plants, as of animals, are quaternary, consisting of four elements, — carbon, hydrogen, oxygen, and nitrogen. Cellulose (woody fiber), starch, and chlorophyl (green coloring matter) are eminently vegetable products, but not distinctive; for cellulose is wanting in some plants, as some fungi, and present in some animals, as tunicates; starch, under the name of glycogen, is found in the liver and brains of mammals, and chlorophyl gives color to the fresh-water polyp. Still, it holds good, generally, that plants consist mainly of cellulose, dextrin, and starch; while animals are mainly made up of albumen, fibrin, and gelatin; that nitrogen is more abundant in animal tissues, while in plants carbon is predominant.

(3) **Form.** — No outline can be drawn which shall be common to all animals or all plants. The lowest members of each group have no fixed shape. The spores of Confervæ can hardly be distinguished from animalcules; the compound and fixed animals, sea mat and

sea moss (Polyzoa), and corals, often resemble vegetable forms, although in structure widely removed from plants. Similar conditions of life are here accompanied by an external likeness. In free-living animals this resemblance is not found.

(4) **Structure.** — A plant is the multiplication of the unit—a cell with a cellulose wall. Some simple animals have a similar simple cellular structure; and all animal tissues, while forming, are cellular. But this character, which is permanent in plants, is generally transitory in animals. In the more highly organized tissues the cells are so united as partly or wholly to lose their individuality, and the characteristic part of the tissue is the intercellular substance, while the cells themselves are small and unimportant, or else the cells are fused together and their dividing walls become indistinct, as in glandular tissue. Excepting the lowest forms, animals are more composite than plants, *i.e.*, their organs are more complex and numerous, and more specially devoted to particular purposes. Repetition of similar parts is a characteristic of plants; and when found in animals, as the angleworm, is called *vegetative repetition*. Differentiation and specialization are characteristic of animals. Most animals, moreover, have fore-and-aft polarity; in contrast, plants are up-and-down structures, though in this respect they are imitated by radiate animals, like the starfish. Plants are continually receiving additional members; most animals soon become perfect.

(5) **Physiology.** — In their modes of nutrition, plants and animals stand widest apart. A plant in the seed and an animal in the egg exist in similar conditions: in both cases a mass of organic matter accompanies the germ. When this supply of food is exhausted, both seek nourishment from without. But here analogy

ends: the green plant feeds on mineral matter, the animal on organic. Some plants have the power to form chlorophyl, the green coloring matter of leaves, which uses the energy of the sunlight to form starch out of the inorganic substances, — carbon dioxide and water. They are able also to form albuminoid matter out of inorganic substances. A very few animals which have a substance identical with or allied to chlorophyl have the same power, but in general animals are dependent for their food on the compounds put together in plants. Colorless plants, as fungi, possessing no chlorophyl, feed, like animals, on organic compounds. No living being is able to combine the simple elements — carbon, oxygen, hydrogen, and nitrogen — into organic compounds.

The food of plants is gaseous (carbon dioxide and ammonia) or liquid (water containing substances in solution), that of animals usually more or less solid, though solid substances must be changed to liquids before being capable of absorption into the tissues. The plant, then, absorbs these foods through its outer surface, while the animal takes its nourishment in larger or smaller masses, and digests it in a special cavity. A few exceptions, however, occur, since certain animals, as the tapeworm, have no digestive tract but absorb liquid food through the surface of the body.

Plants are ordinarily fixed, their food is brought to them, and a large share of their work, the formation of organic compounds, is done by the energy of the sunlight; while animals are usually locomotive, must seek their food, and are unable to utilize the general forces of nature as the plant does. The plant is thus able to grow much more than the animal, as very little of the nourishment received is used to repair waste, while in most animals the time soon comes when waste and re-

pair are approximately equal. But in both all work done is paid for by waste of substance already formed.

In combining carbon dioxide and water to form starch the plant sets oxygen free ($6(\text{CO}_2) + 5(\text{H}_2\text{O}) = \text{C}_6\text{H}_{10}\text{O}_5 + 6(\text{O}_2)$): in oxidizing starch or other food the animal uses oxygen and sets carbon dioxide free. The green plant in the sunlight, then, gives off oxygen and uses carbon dioxide, while plants, which have no chlorophyl, at all times, and all plants in the darkness, use oxygen and give off carbon dioxide, like an animal. Every plant begins life like an animal—a consumer, not a producer: not till the young shoot rises above the soil, and unfolds itself to the light of the sun, at the touch of whose mystic rays chlorophyl is developed, does real, constructive vegetation begin; then its mode of life is, in a sense, reversed; since more carbon is combined than liberated, and more oxygen set free than maintained.

Most plants, and many animals, multiply by budding and division; on both we practice grafting; in both the cycle of life comes round again to the ovule or ovum. Do annuals flower but to die? Insects lay their eggs in their old age.

Both animals and plants have sensibility. This is one of the fundamental physiological properties of protoplasm. But in plants the protoplasm is scattered and buried in rigid structures: feeling is, therefore, dull. In animals irritability is a highly developed property of certain organs, and so feeling, like electricity rammed into Leyden jars, goes off with a flash.⁶⁵ Plants probably never possess consciousness or volition, as the higher animals do.

The self-motion of animals and the rooted state of plants is a very general distinction; but it fails where we need it most. It is a characteristic of living things

to move. The protoplasm of all organisms is unceasingly active.⁶⁶ Besides this internal movement, myriads of plants, as well as animals, are locomotive. Rambling diatoms, writhing oscillaria, and the agile spores of cryptogams crowd our waters, their organs of motion (cilia and pseudopodia) being of the very same character as in microscopic animals; while sponges, corals, oysters, and barnacles are stationary. A contractile vesicle is not exclusively an animal property, for the several fresh-water algæ, as *Gonium*, have it. The muscular contractions of the highest animals and the sensible motions of plants are both due to changes in the protoplasm in their cells. The ciliary movements of animals and of microscopic plants are precisely similar, and in neither case necessarily indicate consciousness or self-determining power.

Plants, as well as animals, need a season of repose. Both have their epidemics. On both, narcotic and acrid poisons produce analogous results. Are some animals warm-blooded? In germination and flowering, plants evolve heat—the stamens of the arum, *e.g.*, showing a rise of 20° F. In a sense, an oak has just as much heat as an elephant, only the miserly tree locks up the sunlight in solid carbon.

At present, any boundary of the animal kingdom is arbitrary. “We cannot distinguish the vegetable from the animal kingdom by any complete and precise definition. Although ordinary observation of their usual representatives may discern little that is common to the two, yet there are many simple forms of life which hardly rise high enough in the scale of being to rank distinctively either as plant or animal; there are undoubted plants possessing faculties which are generally deemed characteristic of animals; and some plants of the highest grade share in these endowments.”⁶⁷

CHAPTER VI

RELATION BETWEEN MINERALS, PLANTS, AND ANIMALS

THERE are no independent members of creation : all things touch upon one another. The matter of the living world is identical with that of the inorganic. The plant, feeding on the minerals, carbon dioxide, water, and ammonia, builds them up into complex organic compounds, as starch, sugar, gum, cellulose, albumen, and gluten. When the plant is eaten by the animal, these substances are used for building up tissues, supplying energy, repairing waste, laid up in reserve as glycogen and fat, or oxidized in the tissues to produce heat. The albuminoids are essential for the formation of tissues, like muscle, nerve, cartilage ; the ternary compounds help in repairing waste, while both produce heat. When oxidized, whether for work or warmth, these complex compounds break up into the simple compounds, — water, carbon dioxide, and (ultimately) ammonia, and as such are returned to earth and air from the animal. Both plant and animal end their life by going back to the mineral world : and thus the circle is complete — from dust to dust. Plants compress the forces of inorganic nature into chemical compounds ; animals liberate them. Plants produce ; animals consume. The work of plants is synthesis, a building-up ; the work of animals is analysis, or destruction. Without plants, animals would perish ; without animals, plants had no need to be.

CHAPTER VII *

LIFE

ALL forces are known by the phenomena which they cause. So long as the animal and plant were supposed to exist in opposition to ordinary physical forces or independently of them, a *vital force* or principle was postulated by which the work of the body was performed. It is now known that most, if not all, of the phenomena manifested by a living body are due to one or more of the ordinary physical forces,—heat, chemical affinity, electricity, etc. There is no *work* done which demands a vital force.

The common modern view is that vitality is simply a collective name for the sum of the phenomena displayed by living beings. It is neither a force nor a thing at all, but is an abstraction, like goodness or sweetness; or, to use Huxley's expression, to speak of vitality is as if one should speak of the horology of a clock, meaning its time-keeping properties.

A third theory is still possible. The combination of elements into organic cells, the arrangement of these cells into tissues, the grouping of these tissues into organs, and the marshaling of these organs into plans of structure, call for some further shaping, controlling power to effect such wonderful coördination. Moreover, the manifestation of feeling and consciousness is a mystery which no physical hypothesis has cleared up. The simplest vital phenomenon has in it something over

* See Appendix.

and above the known forces of the laboratory.⁶⁸ If the vital machine is given, it works by physical forces; but to produce it and keep it in order needs, so far as we now know, more than mere physical force. To this controlling power we may apply the name *vitality*.

Life is exhibited only under certain conditions. One condition is the presence of a physical basis called *protoplasm*. This substance is found in all living bodies, and, so far as we know, is similar in all—a viscid, transparent, homogeneous, or minutely granular, albuminoid matter. Life is inseparable from this protoplasm; but it is dormant unless excited by some external stimulants, such as heat, light, electricity, food, water, and oxygen. Thus, a certain temperature is essential to growth and motion; taste is induced by chemical action, and sight by luminous vibrations.

The essential manifestations of animal life may be reduced to four: *contractility*; *irritability*, or the power of receiving and transmitting impressions; the *power of assimilating food*; the *power of reproduction*. All these powers are possessed by protoplasm, and so by all animals: all move, feel, grow, and multiply. But some of the lowest forms are without any other trace of organs than is found in a simple cell; they seem to be almost as homogeneous and structureless as a drop of jelly. They could not be more simple. They are devoid of muscles, nerves, and stomach; yet they have all the fundamental attributes of life,—moving, feeling, eating, and propagating their kind. The animal series, therefore, begins with forms that feel without nerves, move without muscles, and digest without a stomach, protoplasm itself having all these properties: in other words, *life is the cause of organization, not the result of it*. Animals do not live because they are organized, but are organized because they are alive.

CHAPTER VIII *

ORGANIZATION

WE have seen that the simplest living thing is a formless speck of protoplasm, without distinctions of structure, and therefore without distinctions of function, all parts serving all purposes — mouth, stomach, limb, and lung — indiscriminately. There is no separate digestive cavity, no separate respiratory, muscular, or nervous systems. Every part will successively feed, feel, move, and breathe. Just as in the earliest state of society all do everything, each does all. Every man is his own tailor, architect, and lawyer. But in the progress of social development the principle of the division of labor emerges. First comes a distinction between the governing and governed classes; then follow and multiply the various civil, military, ecclesiastical, and industrial occupations.

In like manner, as we advance in the animal series, we find the body more and more heterogeneous and complex by a process of *differentiation*, i.e., setting apart certain portions of the body for special duty. In the lowest forms, the work of life is carried on by very simple apparatus. But in the higher organisms every function is performed by a special organ. For example, contractility, at first the property of the entire animal, becomes centered in muscular tissue; respiration, which in simple beings is effected by the whole surface, is specialized in lungs or gills; sensibility, from being

* See Appendix.

common to the whole organism, is handed over to the nerves. An animal, then, whose body, instead of being uniform throughout, is made up of different parts for the performance of particular functions, is said to be *organized*. And the term is as applicable to the slightly differentiated cell as to complex man. Organization is expressed by single cells, or by their combination into tissues and organs.

I. Cells. — A cell is the simplest form of organized life. In general, it is a microscopic globule, consisting

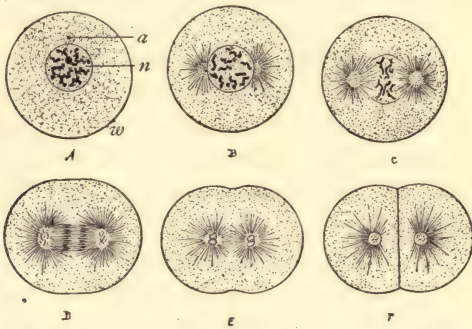


FIG. 198. — *A*, diagram of a cell; *w*, cell wall, with inclosed cytoplasm; *n*, nucleus, consisting of nuclear membrane inclosing granular substance, in which are seen a spherical *nucleolus* and several irregular masses of *chromatin*; *a*, attraction sphere containing a centrosome. *B-F*, changes which take place in the cell during fission.

of a delicate membrane inclosing a minute portion of protoplasm. The very simplest kinds are without granules or signs of circulation; but usually the protoplasm is granular, and contains a defined separate mass called the *nucleus*, within which are sometimes seen one or two, rarely more, dark, round specks, named *nucleoli*. The enveloping membrane is extremely thin, transparent, and structureless; it is only an excretion of dead matter acting as a boundary to the cell contents.⁶⁹ The nucleus generally lies near the center of the protoplasm, and is the center of activity.

Cells vary greatly in size, but are generally invisible to the naked eye, ranging from $\frac{1}{500}$ to $\frac{1}{10000}$ of an inch in diameter. About 4000 of the smallest would be necessary to cover the dot of this letter *i*. The natural form of isolated cells is spherical; but when they crowd each other, as seen in bone, cartilage, and muscle, their outlines become angular, either hexagonal or irregular.

Within the narrow boundary of a simple sphere, the cell membrane, are exhibited all the essential phenomena of life, — nutrition, sensation, development, and reproduction. The physiology of these minute organisms is of peculiar interest, since all animal structure is but the multiplication of the cell as a unit, and the whole life of an animal is that of the cells which compose it: in them and by them all its vital processes are carried on.⁷⁰

The structure of an animal cell can be seen in blood corpuscles, by diluting with a weak (.6 per cent) solution of salt a drop of blood from a frog, and placing it under the microscope. (See Fig. 260.) With this may be compared vegetable cells as seen in a drop of fluid yeast or a drop of water into which pollen grains from some flower have been dusted.

2. Tissues. — There are organisms of the lowest grade (as *Paramecium*, Fig. 9) which consist of a single cell, living for and by itself. In this case, the animal and cell are identical: the *Paramecium* is as truly an individual as the elephant. But all animals, save these unicellular beings, are mainly aggregations of cells; for the various parts of a body are not only separable by the knife into bones, muscles, nerves, etc., but these are susceptible of a finer analysis by the microscope, which shows that they arise from the development and union of cells. These cellular fabrics, called *tissues*, differ from one another both chemically and structurally, but agree in being permeable to liquids — a property which

secures the flexibility of the organs so essential to animal life. Every part of the human body, for example, is moist; even the hairs, nails, and cuticle contain water. The contents as well as the shape of the cells are usually modified according to the tissue which they form: thus, we find cells containing earthy matter, iron, fat, mucus, etc.

In plants, the cell generally retains its characters well defined; but in animals (after the embryonic period) the cell usually undergoes such modifications that its structural features become altered. The cells are connected together or enveloped by an intercellular substance (*matrix*), which may be watery, soft, and gelatinous, firmer and tenacious, still more solid and hyaline, or hard and opaque. In the fluids of the body, as the blood, the cells are separate; *i.e.*, the matrix is fluid. But in the solid tissues they are held together by intercellular substance.

In the lowest forms of life, and in all the higher animals in their earliest embryonic state, the cells of which they are composed are not transformed into differentiated tissues: definite tissues make their first appearance in the sponges, and they differ from one another more and more widely as we ascend the scale of being. In other words, the bodies of the lower and the immature animals are more uniform in composition than the higher or adult forms. In the vertebrates only are all the following tissues found represented:—

(1) **Epithelial Tissue.**—This is the simplest form of cellular structure. It covers all the free surfaces of the body, internal and external, so that an animal may be said to be contained between the walls of a double bag. That which is internal, lining the mouth, windpipe, lungs, blood vessels, gullet, stomach, intestines—in fact, every cavity and canal—is called *epithelium*. It is a

very delicate skin, formed of flat or cylindrical cells, and in some parts (as in the windpipe of air-breathing animals, and along the gills of the oyster) is covered with cilia, or minute hairlike portions of protoplasm, about $\frac{1}{6000}$ of an inch long, which are incessantly moving. Continuous with this inner lining of the body (as seen on the lip), and covering the outside, is the *epidermis* or *cuticle*. It is the outer layer of the "skin," which we can remove by a blister, and in man varies in thickness from $\frac{1}{800}$ of an inch on the cheek to $\frac{1}{10}$ on the sole of the foot.

It is constantly wearing off at the surface, and as constantly being replenished from the deeper portion; and in the process of growth and passage outward, the cells change from the spherical form to dead horny scales (seen in scurf

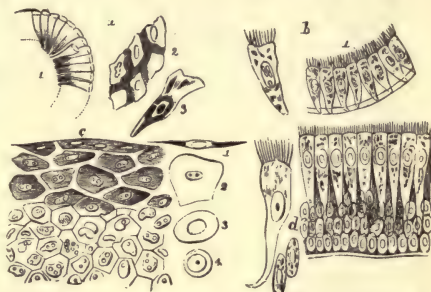


FIG. 199. — Various kinds of Epithelium Cells magnified; *a*, columnar, from small intestine; *3*, a single cell, showing nucleus; *b*, ciliated, from one of the small air-tubes; *d*, the same, from the windpipe, with single cell magnified, about 200 times; *c*, squamous, from eyelid of a calf, showing changes of form, from the deep to superficial cells, *1* being the scurf.

and dandruff). In the lower layer of the cuticle we find the pigment cells, characteristic of colored races. Neither the epidermis nor the corresponding internal tissue (epithelium) has any blood vessels or nerves. The epithelial tissue, then, is simply a superficial covering, bloodless and insensible, protecting the more delicate parts underneath, or, as in the alimentary canal, producing mucus and digestive juices. Hairs, horns, hoofs, nails, claws, corns, beaks, scales, tortoise shell, the wings of insects, etc., are modifications of the epidermis.

The next three sorts of tissue are characterized by a

great development of the intercellular substance, while the cells themselves are very slightly modified.

(2) **Connective Tissue.**— This is the most extensive tissue in animals, as it is the great connecting medium by

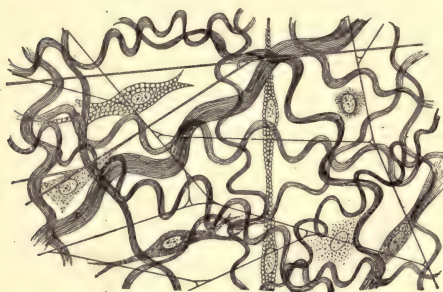


FIG. 200. — Connective Tissue, showing areolar structure.

which the different parts are held together. Could it be taken out entire, it would be a complete mold of all the organs. It surrounds the bones, muscles, blood vessels, nerves,

and glands, and is the substance of the ligaments and tendons, and forms a large portion of "true skin,"

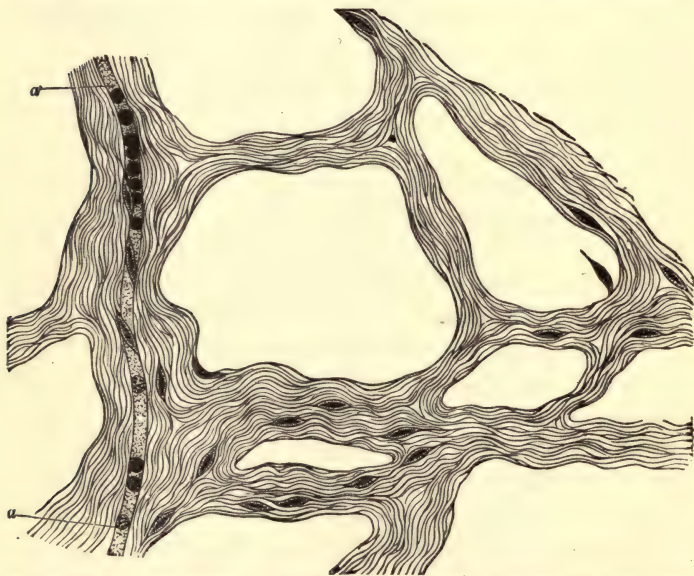


FIG. 201. — Connective Tissue from human peritoneum; highly magnified; *a*, blood vessel.

mucous membrane, etc. It varies in character, being soft, tender, and elastic, or dense, tough, and generally unyielding. In the former state, it consists of innumerable fine white and yellow fibers, which interlace in all directions, leaving irregular spaces, and forming a loose, spongy, moist web. In the latter the fibers are condensed into sheets or parallel cords, having a wavy, glistening appearance. Such structures are the fasciæ and tendons. Connective tissue is not very sensitive. It contains *gelatin* — the matter which tans when hide is made into leather. In this tissue the intercellular



FIG. 202. — Hyaline Cartilage, Diagram: *a*, cartilage cell; *b*, cell about to divide; *c*, cell divided into two; *d*, into four parts. The space between the cells is filled with transparent intercellular substance; highly magnified.

substances take the form of fibers. The *white* fibers are inelastic, and from $\frac{1}{40000}$ to $\frac{1}{24000}$ of an inch in diameter. They are best seen in the tendons. The *yellow* fibers are elastic, very long, and from $\frac{1}{21000}$ to $\frac{1}{4000}$ of an inch in diameter, and branched. Con-



FIG. 203. — Longitudinal section through area of ossification from long bone of human embryo.

nective tissue appears areolar, *i.e.*, shows interspaces, only under the microscope.

(3) **Cartilaginous Tissue.** — This tissue, known also as “gristle,” is composed of cells embedded in a granular or hyaline substance, which is dense, elastic, bluish white, and translucent. It is found where strength, elasticity, and insensibility are wanted, as at the joints. It also takes the place of the long bones in the embryo. When cartilage is mixed with connective tissue, as in the ear, it is called *fibro-cartilage*.

(4) **Osseous Tissue.** — This hard, opaque tissue, called *bone*, differs from the former two in having the inter-

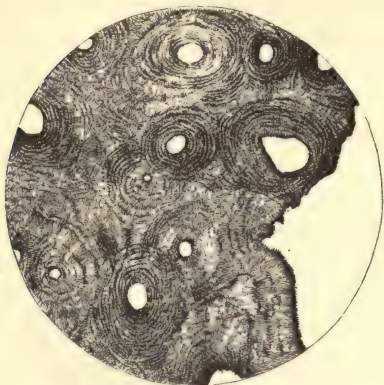


FIG. 204. — Transverse section of a Bone (Human Femur), $\times 50$, showing Haversian canals.

cellular spaces or meshes filled with phosphate of lime and other earths, instead of a hyaline or fibrous substance. It may be called *petrified tissue* — the quantity of earthy matter, and therefore the brittleness of the bone, increasing with the age of the animal.

If a chicken bone be left in dilute muriatic acid several days, it may be tied into a knot, since the acid has dissolved the lime, leaving nothing but cartilage and connective tissue. If a bone be burned, it becomes light, porous, and brittle, the lime alone remaining.⁷¹

Bone is a very vascular tissue; that is, it is traversed by minute blood vessels and nerves, which pass through a network of tubes, called *Haversian canals*.

The canals average $\frac{1}{1000}$ of an inch, being finest near the surface of the bone, and larger farther in, where they form a cancellated or spongy



FIG. 205. — Frontal Bone of Human Skull under the microscope, showing lacunæ and canaliculi.

farther in, where they form a cancellated or spongy

structure, and finally merge (in the long bones) into the central cavity containing the marrow. Under the microscope, each canal appears to be the center of a multitude of *laminæ*, or plates, arranged around it. Lying between these plates are little cavities, called *lacunæ*, which are connected by exceedingly fine tubes, or *canaliculi*. The two represent the spaces occupied by the original cells of the bone, and differ in shape and size in different animals.

True bone is found only in vertebrates, or backboned animals.

(5) **Dental Tissue.** — Like bone, a tooth is a combination of earthy and animal matter. It may be called petrified skin. In the higher animals, it consists of three parts :

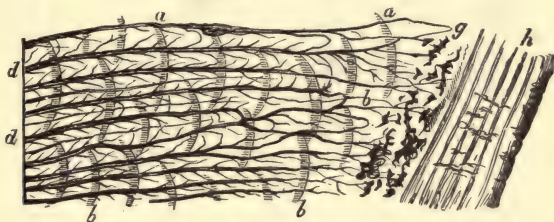


FIG. 206. — Highly magnified section of Dentine and Cement, from the fang of a Human Molar: *a*, *b*, marks of the original dental pulp; *d*, dentinal tubes, terminating in the very sensitive, modified layer, *g*; *h*, cement.

dentine, forming the body of the tooth, and always present; *enamel*, capping the crown; and *cement*, covering the fangs (Fig. 229). The last is true bone, or osseous tissue. Dentine resembles bone, but differs in having neither *lacunæ* nor (save in shark's teeth) *canaliculi*. It shows, in place of the former, innumerable parallel tubes, reaching from the outside to the pulp cavity within. The "ivory" of elephants consists of dentine. Enamel is the hardest substance in the body, and is composed of minute six-sided fibers, set closely together. It is

wanting in the teeth of most fishes, snakes, sloths, armadillos, sperm whales, etc.

True dental tissue is confined to vertebrates.

(6) **Adipose Tissue.** — Certain cells become greatly enlarged and filled with fat, so that the original protoplasm occupies a very small part of the space within the cell membrane. These cells are united into masses by connective tissue, in the skin (as in the “blubber” of whales), between the muscles (as in “streaky” meat), or in

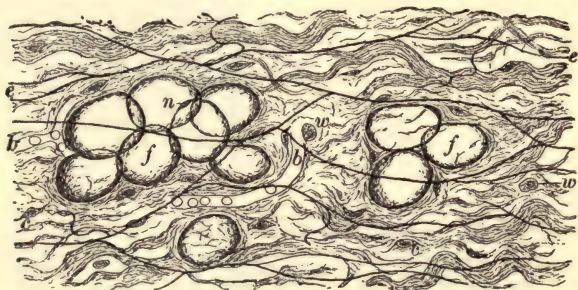


FIG. 207. — Fat Cells embedded in Subcutaneous Areolar Tissue. *f*, fat cells; *n*, nucleus; *c*, connective-tissue corpuscles; *w*, migratory cells; *e*, elastic fibers; *b*, capillary blood vessel.

the abdominal cavity, in the omentum, mesentery, or about the kidneys. The marrow of bones is an example. Globules of fat occur in many mollusks and insects; but true adipose tissue is found only in backboned animals, particularly in the herbivorous. In the average man, it constitutes about $\frac{1}{20}$ part of his weight, and a single whale has yielded 120 tons of oil. The fat of animals has the different names of oil, lard, tallow, suet, spermaceti, etc. It is a reserve of nutriment in excess of consumption, serving also as a packing material, and as a protection against cold.

(7) **Muscular Tissue.** — If we examine a piece of lean meat, we find it is made up of a number of *fasciculi*, or bundles of fibers, placed side by side, and bound together

by connective tissue. The microscope informs us that each fiber is itself a bundle of smaller fibers; and when one of these is more closely examined, it is found to consist of a delicate, smooth tube, called the *sarcolemma*, which is filled with very minute, parallel fibrils, averaging $\frac{1}{10000}$ of an inch in diameter, the whole having a striated aspect and containing numerous nuclei. Tissue of this description constitutes all ordinary muscle, or "lean meat," and is marked by regular cross lines, or *striae*.



FIG. 209. — Striated Muscular Fibers, from the heart of Man, divided by transverse septa into separate nucleated portions; much magnified.

Besides this striated muscular tissue, there exist, in the coats of the stomach, intestines, blood vessels, and some other parts of vertebrates, *smooth* muscular fibers, which show a single nucleus under the microscope, and do not break up into fibrils (Fig. 319). The gizzards of fowls exhibit this form.

All muscle has the property of shortening itself when excited; but the contraction of the striated kind is under the control of the will, while the movement of the smooth fibers is involuntary.⁷² Muscles are well supplied with arteries, veins, and nerves; but the color is due to a peculiar pigment, not to the blood.

Muscular tissue is found in all animals from the coral to man.

(8) **Nervous Tissue.** — Nervous Tissue consists of large,

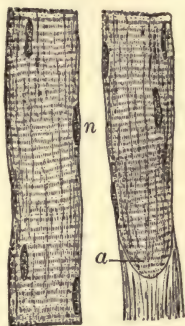


FIG. 208. — Voluntary Muscle, portions of two fibers showing the characteristic transverse markings; the lighter band is divided by the row of minute beads constituting the intermediate disk: *a*, termination of muscular substance and attachment of adjoining fibrous tissue; *n*, nuclei of muscle fibers.

nucleated cells, which give off one to several processes, the latter serving as paths of communication between the cells themselves or between the cells and the various motor, sensory, and other organs with which they are connected. Such threads of nerve tissue are called



FIG. 210. — Portion of two Nerve Fibers: *a*, medullary sheath; *c*, nucleus of neurilemma; *R*, annular constriction.

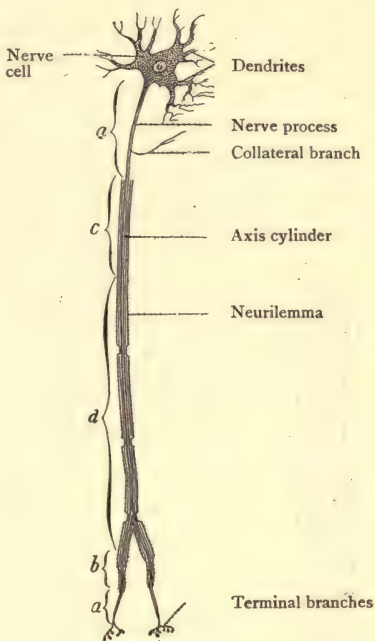


FIG. 211. — Diagram of a Neuron: *a*, nerve process; *b*, neurilemma; *c*, medullary sheath; *d*, neurilemma and medullary sheath, combined.

nerve fibers, and each consists essentially of a prolongation of the protoplasmic substance of which the cell body is composed. The cells vary from $\frac{1}{3500}$ to $\frac{1}{250}$ of an inch in diameter, and are found in the nerve centers (Fig. 329), the gray portion of the brain, spinal cord, and other ganglia. The fibers vary in structure. In the lowest Metazoa they are merely naked threads of

protoplasm. In the higher animals each thread, known as the *axis cylinder*, is surrounded by a delicate, transparent covering called the *neurilemma*, analogous to the sarcolemma of muscle tissue. In the vertebrates, the protoplasmic threads found in many parts of the nervous system have an additional covering made of fatty material, which lies between the axis cylinder and the neurilemma, and is known as the *medullary sheath*. These are called *medullated* nerve fibers, as distinguished

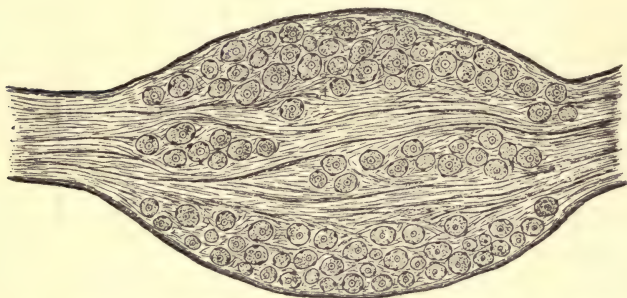


FIG. 212. — Spinal Ganglion, in longitudinal section, from Cat; the groups of nerve cells lie embedded among the bundles of the nerve fibers.

from the nonmedullated or those which lack the medullary sheath. Fibers of the former kind are found in the white substance of the brain and spinal cord, and run to the muscles and organs of sense. Nonmedullated fibers are found in the gray substance of the nervous system. The axis cylinders are destitute of a sheath in the neighborhood of the cell body. Scattered along the fibers nuclei are found. The large nerve fibers may be $\frac{1}{1200}$ of an inch in diameter, and some are supposed to extend from cell bodies situated in the lower part of the spinal cord down the leg to the foot.

A bundle of nerve fibers surrounded by connective tissue constitutes a *nerve* in the anatomical sense.

3. Organs and their Functions.—Animals, like plants, grow, feel, and move; these three are the capital facts of every organism. Besides these there may be some peculiar phenomena, as motion and will.

Life is manifested in certain special operations, called *functions*, performed by certain special parts, called *organs*. Thus, the stomach is an organ, whose function is digestion. A single organ may manifest vitality, but it does not (save in the very lowest forms) show forth the whole life of the animal. For, in being set apart for a special purpose, an organ takes upon itself, so to speak, to do something for the benefit of the whole animal, in return for which it is absolved from doing many things. The stomach is not called upon to circulate or purify the blood.

There may be functions without special organs, as the amœba digests, respire, moves, and reproduces by its general mass. But, as we ascend the scale of animal life, we pass from the simple to the complex: groups of cells or tissues, instead of being repetitions of each other, take on a difference, and become distinguished as special parts with specific duties. The higher the rank of the animal, the more complicated the organs. The more elaborated the structure, the more complicated the functions. But in all animals, the functions are performed under conditions essentially the same. Thus, respiration in the sponge, the fish, and in man has one object and one means, though the methods differ. A function, therefore, is a group of similar phenomena effected by analogous structures.

The life of an animal consists in the accumulation and expenditure of force. The tissues are storehouses of power, which, as waste goes on, is given off in various forms. Thus, the nervous tissue generates nerve force; the muscles, motion. If we contemplate the phenomena

presented by a dog, the most obvious fact is his power of moving from place to place, a power produced by the interplay of muscles and bones. We observe, also, that his motions are neither mechanical nor irregular; there is method in his movement. He has the power of willing, seeing, hearing, feeling, etc.; and these functions are accomplished by a delicate apparatus of nerves.

But the dog does not exhibit perpetual motion. Sooner or later he becomes exhausted, and rest is necessary. Sleep gives only temporary relief. In every exercise of the muscles and nerves there is a consumption or waste of their substance. The blood restores the organs, but in time the blood itself needs renewal. If not renewed, the animal becomes emaciated, for the whole body is laid under contribution to furnish a supply. Hence the feelings of hunger and thirst, impelling the creature to seek food. Only this will maintain the balance between waste and repair. We notice, therefore, an entirely different set of functions, involving, however, the use of motion and will. The dog seizes a piece of meat, grinds it between his teeth and swallows it. It passes into the stomach, where it is digested, and then into the intestine, where it is further changed; there the nourishing part is absorbed, and carried to the heart, which propels it through tubes, called blood vessels, all over the body. In this process of digestion, certain fluids are required, as saliva, gastric juice, and bile: these are secreted by special organs, called glands. Moreover, since not all the food eaten is fitted to make blood, and as the blood itself, in going around the body, acts like a scavenger, picking up worn-out particles, we have another function, that of excretion, or removal of useless matter from the system. The kidneys and lungs

do much of this ; but the lungs do something else. They expose the blood to the air, and introduce oxygen, which, we shall find, is essential to the life of every animal.

These centripetal and centrifugal movements in the body — throwing in and throwing out — are so related and involved, especially in the lower forms, that they can not be sharply defined and classified. It has been said that every dog has two lives, — a *vegetative* and an *animal*. The former includes the processes of digestion, circulation, respiration, secretion, etc., which are common to all life ; while the functions included by the latter, as motion, sensation, and will, are characteristic of animals. The heart is the center of the vegetative life, and the brain is the center of the animal life. The aim of the vegetative organs is to nourish the individual, and reproduce its kind ; the organs of locomotion and sense establish relations between the individual and the world without. The former maintain life ; the others express it. The former develop, and afterward sustain, the latter. The vegetative organs, however, are not independent of the animal ; for without muscles and nerves we could not procure, masticate, and digest food. The closer the connection and dependence between these two sets of organs, the higher the rank.⁷³

All the apparatus and phenomena of life may be included under the heads of —

NUTRITION,
MOTION,
SENSATION,
REPRODUCTION.

These four are possessed by all animals, but in a variety of ways. No two species have exactly the same mechanism and method of life. We must learn to dis-

tinguish between what is necessary and what is only accessory. That only is essential to life which is common to all forms of life. Our brains, stomachs, livers, hands, and feet are luxuries. They are necessary to make us human, but not living, beings. Half of our body is taken up with a complicated system of digestion; but the amœba has neither mouth nor stomach. We have an elaborate apparatus of motion; the adult oyster can not stir an inch.

Nutrition, Motion, and Sensation indicate three steps up the grade of life. Thus, the first is the prominent function in the coral, which simply "vegetates," the powers of moving and feeling being very feeble. In the higher insect, as the bee, there is great activity with simple organs of nutrition. In the still higher mammal, as man, there is less power of locomotion, though the most perfect nutritive system; but both functions are subordinate to sensation, which is the crowning development.

In studying the comparative anatomy and physiology of the animal kingdom, our plan will be to trace the various organs and functions, from their simplest expression upward to the highest complexity. Thus *Nutrition* will begin with absorption, which is the simplest method of taking food; going higher, we find digestion, but in no particular spot in the body; next, we see it confined to a tube; then to a tube with a sac, or stomach; and, finally, we reach the complex arrangement of the higher animals.

CHAPTER IX

NUTRITION

Nutrition is the earliest and most constant of vital operations. So prominent is the nutritive apparatus, that an animal has been likened to a moving sac, organized to convert foreign matter into its own likeness, to which the complex organs of animal life are but auxiliaries. Thus, the bones and muscles are levers and cords to carry the body about, while the nervous system directs its motions in quest of food.

The objects of nutrition are growth, repair, propagation, and supplying energy to perform the work, or functions, of the body. The first object of life is to grow, for no animal is born finished. Some animals, like plants, grow as long as they live; but the majority soon attain a fixed size. In all animals, however, without exception, food is wanted for another purpose than growth, namely, to repair the waste which is constantly going on. For every exercise of the muscles and nerves involves the death and decay of those tissues, as shown by the excretions. The amount of matter expelled from the body, and the amount of nourishment needed to make good the loss, increase with the activity of the animal. The supply must equal the demand, in order to maintain the life of the individual; and as an animal can not make food, it must seek it from without. Not only the muscles and nerves are wasted by use, but every organ in the body; so that the whole structure needs constant renewal. An

animal begins to die the moment it begins to live. The function of nutrition, therefore, is *constructive*, while motion and sensation are *destructive*.

Another source of demand for food is the production of germs, to propagate the race, and the nourishment of such offspring in the egg and infantile state. This reproduction and development of parts which can maintain an independent existence is a *vegetative* phenomenon (for plants have it), and is a part of the general process of nutrition. But it will be more convenient to consider it hereafter (Chapters XXII., XXIII.). Still another necessity for aliment among the higher animals is the maintenance of bodily heat. This will be treated under the head of Respiration.

For the present, we will study nutrition, as manifested in maintaining the life of an adult individual.

In all animals, this process essentially consists in *the introduction of food, its conversion into tissue, its oxidation, and the removal of worn-out material*.

1. The food must be procured, and swallowed. (Ingestion.)

2. The food must be dissolved. (Digestion.)

3. The nutritive fluid must be taken up, and then distributed all over the body. (Absorption and circulation.)

4. The tissues must repair their parts wasted by use, by transforming a portion of the blood into living matter like themselves. (Assimilation.)

5. Certain matters must be eliminated from the blood, some to serve a purpose, others to be cast out of the system. (Secretion and excretion.)

6. In order to produce work and heat, the food must be oxidized, either in the blood or in the tissues, after assimilation. The necessary oxygen is obtained through exposure of the blood to the air in the lungs. (Respiration in part.)

7. The waste products of this oxidation taken up by the blood must be got rid of ; some from the lungs (carbon dioxide, water), some from the kidneys (water, urea, mainly), some from the skin (water, salines). (Respiration in part, excretion.)

The mechanism to accomplish all this in the lowest forms of life is exceedingly simple, a single cavity and surface performing all the functions. But in the majority of animals the apparatus is very complicated : there is a set of organs for the prehension of food ; another for digestion ; a third, for absorption ; a fourth, for distribution ; and a fifth, for purification.

CHAPTER X

THE FOOD OF ANIMALS

THE term **food** includes all substances which contribute to nutrition and furnish energy, whether they simply assist in the process, or are actually appropriated, and become tissue. With the food is usually combined more or less indigestible matter, which is separated in digestion.

Food is derived from the mineral, vegetable, and animal kingdoms. Water and salt, for example, are inorganic. The former is the most abundant, and a very essential article of food. Most of the lower forms of aquatic life seem to live by drinking: their real nourishment, however, is present in the water in the form of fine particles. The earthworm, some beetles, and certain savage tribes of men swallow earth; but this, likewise, is for the organic matter which the earth contains. As no animal is produced immediately from inorganic matter, so no animal can be sustained by it.

Nutritious or tissue-forming food comes from the organic world, and is *albuminous*, as the lean meat of animals and the gluten of wheat; *oleaginous*, as animal fat and vegetable oil; or *saccharine*, as starch and sugar. The first is the essential food stuff; no substance can serve permanently for food — that is, can permanently prevent loss of weight in the body — unless it contains albuminous matter. As stated before, all the living tissues are albuminous, and therefore albuminous food is required to supply their waste. Albumen contains

nitrogen, which is necessary to the formation of tissue; fats and sugars are rich in carbon, and therefore serve to maintain the heat of the body, and to repair part of the waste of tissues. Many warm-blooded animals feed largely on farinaceous or starchy substances, which in digestion are converted into sugar. But any animal, of the higher orders certainly, whether herbivorous or carnivorous, would starve if fed on pure albumen, oil, or sugar. Nature insists upon a mixed diet; and so we find in all the staple articles of food, as milk, meat, and bread, at least two of these principles present. As a rule, the nutritive principles in vegetables are less abundant than in animal food, and the indigestible residue is consequently greater. The nutriment in flesh increases as we ascend the animal scale; thus, oysters are less nourishing than fish; fish, less than fowl; and fowl, less than the flesh of quadrupeds.

Many animals, as most insects and mammals, live solely on vegetable food, and some species are restricted to particular plants, as the silkworm to the white mulberry. But the majority of animals feed on one another; such are hosts of the microscopic forms, and nearly all the radiated species, marine mollusks, crustaceans, beetles, flies, spiders, fishes, amphibians, reptiles, birds, and clawed quadrupeds.

A few, as man himself, are omnivorous, *i.e.*, are maintained on a mixture of animal and vegetable food. The use of fire in the preparation of food is peculiar to man, who has been called "the cooking animal." A few of the strictly herbivorous and carnivorous animals have shown a capacity for changing their diet. Thus, the horse and cow may be brought to eat fish and flesh; the sea birds can be habituated to grain; cats are fond of alligator-pears; and dogs take naturally to the plantain. Certain animals, in passing from the young to the

mature state, make a remarkable change of food. Thus, the tadpole feeds upon vegetable matter; but the adult frog is carnivorous, living on insects, worms, and crustaceans.

Many tribes, especially of reptiles and insects, are able to go without food for months, or even years. Insects in the larval, or caterpillar, state are very voracious; but upon reaching the perfect, or winged, state, they eat little — some species taking no food at all, the mouth being actually closed. The males of some rotifers and other tribes take no food from the time of leaving the egg until death.

In general, the greater the facility with which an animal obtains its food, the more dependent is it upon a constant supply. Thus, carnivores endure abstinence better than herbivores, and wild animals than domesticated ones.

CHAPTER XI

HOW ANIMALS EAT

1. The Prehension of Food. — (1) **Liquids.** — The simplest method of taking nourishment, though not the method of the simplest animals, is by absorption through the skin. The tapeworm, for example, living in the intestine of its host, has neither mouth nor stomach, but absorbs the digested food with which its body is bathed (Fig. 37). Many other animals, especially insects, live upon liquid food, but obtain it by suction through a special orifice or tube. Thus, we find a mouth, or sucker, furnished with teeth for lancing the skin of animals, as in the leech; a bristlelike tube fitted for piercing, as in the mosquito; a sharp sucker armed with barbs, to fix it securely during the act of sucking, as in the louse; and a long, flexible proboscis, as in the butterfly (Fig. 221). Bees have a hairy, channeled tongue (Fig. 220), and flies have one terminating in a large, fleshy knob, with or without little “knives” at the base for cutting the skin (Fig. 222); both lap, rather than suck, their food.

Most animals drink by suction, as the ox; and a few by lapping, as the dog; the elephant pumps the water up with its trunk, and then pours it into its throat; and birds (excepting doves) fill the beak, and then, raising the head, allow the water to run down.

Many aquatic animals, whose food consists of small particles diffused through the water, have an apparatus for creating currents, so as to bring such particles within

their reach. This is particularly true of low, fixed forms, which are unable to go in search of their food. Thus, the sponge draws nourishment from the water, which is made to circulate through the system of canals traversing its body by the vibration of flagella, lining parts of the canals (Figs. 14, 15). The microscopic infusoria have cilia surrounding the mouth, with which they draw or drive into the body little currents containing nutritious particles (Figs. 9, 11). Bivalve mollusks, as the oyster and clam, are likewise dependent upon this method of procuring food, the gills and inner surface of the mantle being covered with cilia. So the singular fish, amphioxus (the only example among vertebrates), employs ciliary action to obtain the minute organisms on which it feeds (Fig. 117). The Greenland whale has a mode of ingestion somewhat unique, gulping great volumes of water into its mouth, and then straining out, through its whalebone sieve, the small animals which the water may contain (Fig. 171).

(2) **Solids.** — When the food is in solid masses, whether floating in water or not, the animal is usually provided with prehensile appendages for taking hold of it. The jellylike amœba (Fig. 1) has neither mouth nor stomach, but extemporizes them, seizing its food by means of its soft body. The food then passes through the denser, outer portion of the body into the softer interior, where it is digested. The waste particles are passed out in the reverse direction. In the foraminifers, threadlike projections (pseudopodia) of the body are thrown out which adhere to the prey. The soft jellylike substance

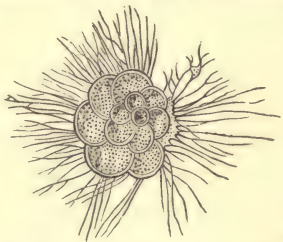


FIG. 213. — A Foraminifer (*Rotalia Veneta*), with pseudopodia extended, $\times 30$.

of the body then flows toward and collects about the food, and digests it (Fig. 213).

A higher type is seen in polyps and jellyfishes, which have hollow tentacles around the entrance to the stomach (Figs. 18, 20, 26). These tentacles are contractile, and some, moreover, are covered with an immense number of minute sacs, in each of which a highly elastic filament is coiled up spirally (lasso cells, nettle cells). When the tentacles are touched by a passing animal, they seize it, and at the same moment throw out their myriad filaments, like so many lassos, which penetrate the skin of the victim, and probably also emit a fluid, which paralyzes it; the mouth, meanwhile, expands to an extraordinary size, and the creature is soon engulfed in the digestive bag.

In the next stage, we find no tentacles, but the food is brought to the mouth by the flexible lobes of the body commonly called *arms*, which are covered with hundreds of minute suckers; and if the prey, as an oyster, is too large to be swallowed, the stomach protrudes, like a proboscis, and sucks it out of its shell. This is seen in the starfish (Fig. 323).

A great advance is shown by the sea urchin, whose mouth is provided with five sharp teeth, set in as many jaws, and capable of being projected so as to grasp, as well as to masticate, its food (Figs. 48, 226).

In mollusks having a single shell, as the snail, the chief organ of prehension is a straplike tongue, covered with minute recurved teeth, or spines, with which the animal rasps its food, while the upper lip is armed with a sharp, horny plate (Fig. 227). In many marine species, as the whelk, the tongue is situated at the end of a retractile proboscis, or muscular tube. In the cuttlefish, we see the sudden development of an elaborate system of prehensile organs. Besides a spinous tongue, it has

a pair of hard mandibles, resembling the beak of a parrot, and working vertically; and around the mouth are eight or ten powerful arms furnished with numerous cup-like suckers. So perfect is the adhesion of these suckers, that it is easier to tear away a limb than to detach it from its hold.

The earthworm swallows earth containing particles of decaying vegetable matter, which it secures with its lips, the upper one being prolonged. Other worms (as *Nereis*) are so constructed that the gullet, which is frequently armed with teeth and forceps, can be protruded to form a proboscis for seizing prey.

The Arthropoda exhibit a great variety of means for procuring nourishment, in addition to the suctorial contrivances already mentioned, the innumerable modifications of the mouth corresponding

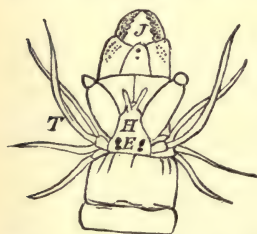


FIG. 215. — *Nereis*—head, with extended proboscis: *J*, jaws; *T*, tentacles; *H*, head; *E*, eyes.

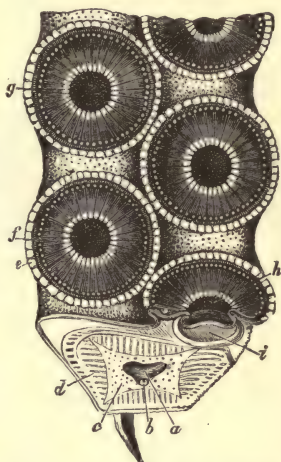


FIG. 214. — Suckers on the Tentacles of a Cuttlefish: *a*, hollow axis of the arm, containing nerve and artery; *c*, cellular tissue; *d*, radiating fibers; *h*, raised margin of the disk around the aperture *f*, *g*, which contains a retractile membrane, or "piston," *i*.

to the diversity of food. Millipedes, caterpillars, and grubs have a pair of horny jaws moving horizontally. The centipede has a second pair of jaws, which are really modified feet, terminated by curved fangs containing a poison duct. The horseshoe crab uses its feet for prehension, and the thighs, or basal joints of its legs, to masticate the food and force it into the stomach.

The first six pairs of legs in the lobster and crab are likewise appropriated to conveying food into the mouth, the sixth being enormously developed, and furnished with powerful pincers. Scorpions have a similar pair

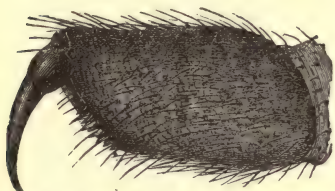


FIG. 216. — One of the Fangs, or Perforated Mandibles, of the Spider, much magnified.

of claws for prehension, and also a pair of small forceps for holding the food in contact with the mouth. In their relatives, the spiders, the claws are wanting, and the forceps end in a fang, or hook, which is perforated to convey venom.⁷⁴

The biting insects, as beetles and locusts, have two pairs of horny jaws, which open sidewise, one above and the other below the oral orifice. The upper pair are called mandibles; the lower, maxillæ. The former are armed with sharp teeth, or with cutting edges, and sometimes are fitted, like the molars of quadrupeds, to grind the food. The maxillæ are usually composed of several parts, some of which serve to hold the food, or to help in dividing it, while others (palpi) are both sensory and prehensile. There is generally present a third pair of jaws — the *labium* — which are united in the middle line, and serve as a lower lip. They also bear palpi. The mantis seizes its prey with its long fore legs, crushes it between its thighs, which are armed with spines, and then delivers it up to the jaws for mastication. All arthropods move their jaws horizontally.

The backboned animals generally apprehend food by means of their jaws, of which there are two, moving vertically. The toothless sturgeon draws in its prey by powerful suction. The hagfish has a single tooth, which it plunges into the sides of its victim, and, thus securing

a firm hold, bores its way into the flesh by means of its sawlike tongue. But fishes are usually well provided with teeth, which, being sharp and curving inward, are strictly prehensile. The fins and tongue are not prehensile. A mouth with horny jaws, as in the turtles, or bristling with teeth, as in the crocodile, is the only means possessed by nearly all amphibians and reptiles for securing food. The toad, frog, and chameleon capture insects by darting out the tongue, which is tipped with glutinous saliva. The constricting serpents (boas) crush their prey in their coils before swallowing; and the venomous snakes have poison fangs. No reptile has prehensile lips. All birds use their toothless beaks in procuring food, but birds of prey also seize with their talons, and woodpeckers, hummers, and parrots with their tongues. The beak varies greatly in shape, being a hook in the eagle, a probe in the woodpecker, and a shovel in the duck.

Among the quadrupeds we find a few special contrivances, as the trunk of the elephant, and the long tongues of the giraffe and ant-eater; but, as a rule, the teeth are the chief organs of prehension, always aided more or less by the lips.

Ruminants, like the ox, having hoofs on their feet, and no upper front teeth, employ the lips and tongue. Such as can stand erect on the hind legs, as the squirrel, bear, and kangaroo, use the front limbs for holding the food and bringing it to the mouth, but

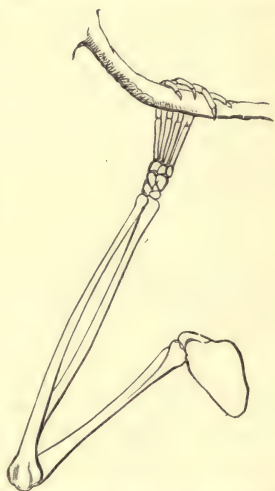


FIG. 217. — Arm of the Thumbless Monkey (*Ateles*).

never one limb alone. The clawed animals, like the cat and lion, make use of their feet in securing prey, all four limbs being furnished with curved retractile claws; but the food is conveyed into the mouth by the movement of the head and jaws. Man and the monkeys employ the hand in bringing food to the mouth, and the lips and tongue in taking it into the cavity. The thumb on the human hand is longer and more perfect than that of the apes and monkeys; but the foot of the latter is also prehensile.

2. The Mouths of Animals. — In the parasites, as the tapeworm, which absorb nourishment through the skin, and insects, as the May fly and botfly, which do all their eating in the larval state, the mouth is either wanting or rudimentary. The amœba, also, has no mouth proper, its food passing through the firmer outside part of the bit of protoplasm which constitutes its body. Mouth and anus are thus extemporized, the opening closing as soon as the food or excrement has passed through.

In the infusoria the "mouth" is a round or oval opening leading through the cuticle and outer layer of protoplasm to the interior of the single cell which makes their body. It is usually bordered with cilia, and situated on the side or at one end of the animal (Figs. 9, 11).

An elliptical or quadrangular orifice, surrounded with tentacles, and leading directly to the stomach, is the ordinary mouth of the polyps and jellyfishes. In those which are fixed, as the actinia, coral, and hydra, the mouth looks upward or downward, according to the position in which the animal is attached (Figs. 17, 34, 236); in those which freely move about, as the jellyfish, it is generally underneath, the position of the animal being reversed (Fig. 22). In some, the margin, or lip, is protruded like a proboscis; and in all it is exceedingly dilatable.

The mouth of the starfish and sea urchin is a simple round aperture, followed by a very short throat. In the starfish, it is inclosed by a ring of hard spines and a membrane. In the sea urchin it is surrounded by a muscular membrane and minute tentacles, and is armed with five sharp teeth, set in as many jaws, resembling little conical wedges (Fig. 226).

Among the headless mollusks, the oral apparatus is very simple, being inferior to that of some of the radiate animals. In the oyster and bivalves generally, the mouth is an unarmed slit — a mere inlet to the esophagus, situated in a kind of hood formed by the union of the gills at their origin, and between two pairs of delicate flaps, or palpi. These palpi make a furrow, along which pass the particles of food drawn in by the cilia, borne by cells which cover the surface of the flaps.

Of the higher mollusks, the little clio (one of the pteropods) has a triangular mouth, with two jaws armed with sharp horny teeth, and a tongue covered with spiny hooklets all directed backward. Some univalves have a simple fleshy tube or siphon.

Others, as the whelk, have an extensible proboscis, which unfolds itself, like the finger of a glove, and carries within it a rasplike tongue,

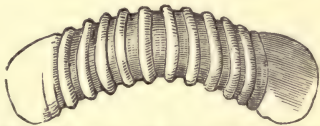


FIG. 218. — Jaw of the Common Snail (*Helix albolabris*) greatly magnified.

which can bore into the hardest shells. Such as feed on vegetable matter, as the snail, have no proboscis, but on the roof of the mouth a curved horny plate fitted to cut leaves, etc., which are pressed against it by the lips, and on the floor of the mouth a small tongue covered with delicate teeth. As fast as the tongue is worn off by use, it grows out from the root.

The mouth of the cuttlefish is the most elevated type below that of the fishes. A broad circular lip nearly

conceals a pair of strong horny mandibles, not unlike the beak of a parrot, but reversed, the upper mandible being the shorter of the two, and the jaws, which are cartilaginous, are imbedded in a mass of muscles, and move vertically. Between them is a fleshy tongue covered with teeth.

The parasitic worms, living within or on the outside of other animals, generally have a sucker at one end or underneath, serving simply for attachment, and another which is perforated. The latter is a true suctorial mouth, being the sole inlet of food. It is often surrounded with hooklets or teeth, which serve both to scarify the victim and secure a firm hold. In the leech, the mouth is a triangular opening with thick lips, the upper one prolonged, and with three jaws. In many worms it is a fleshy tube, which can be drawn in or extended, like the eye stalks of the snail, and contains a dental apparatus inside (Fig. 215).

Millepedes and centipedes have two lateral jaws and a four-lobed lip.

In lobsters and crabs the mouth is situated underneath the head, and consists of a soft upper lip, then a pair of upper jaws provided with a short feeler, below which is a thin bifid lower lip; then follow two pairs of membranous under jaws, which are lobed and hairy; and next, three pairs of foot jaws (Fig. 54). The horseshoe crab has no special jaws, the thighs answering the purpose. The barnacle has a prominent mouth, with three pairs of rudimentary jaws.

With few exceptions, the mouths of insects in the larval state are fitted only for biting, the two jaws being horny shears. But in the winged, or perfect, state, insects may be divided into the masticating (as the beetle) and the suctorial (as the butterfly). In the former group, the oral apparatus consists of two pairs of

horny jaws (*mandibles* and *maxillæ*), which work horizontally between an upper (*labrum*) and an under (*labium*) lip. The *maxillæ* and under lip carry sensitive jointed feelers (*palpi*). The front edge of the *labium* is

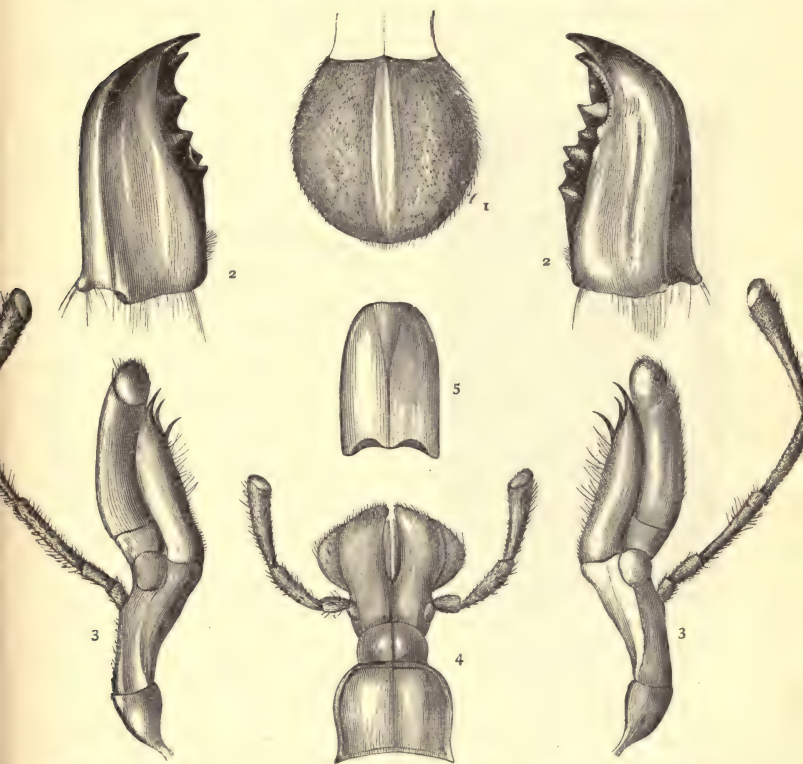


FIG. 219. — Mouth of a Locust, dissected and much magnified: 1, labrum, or upper lip; 2, mandibles; 3, jaws; 4, labium, or lower lip; 5, tongue. The appendages to the *maxillæ* and lower lip are palpi.

commonly known as the tongue (*ligula*).⁷⁵ In such a mouth, the mandibles are the most important parts; but in passing to the suctorial insects, we find that the mandibles are secondary to the *maxillæ* and *labium*, which are the only means of taking food. In the bee

tribe, we have a transition between the biting and the sucking insects—the mandibles “supply the place of trowels, spades, pickaxes, saws, scissors, and knives,” while the maxillæ are developed into a sheath to inclose the long, slender, hairy tongue which laps up the sweets of flowers. In the suctorial butterfly, the lips, mandibles, and palpi are reduced to rudiments, while the

maxillæ are excessively lengthened into a proboscis, their edges locking by means

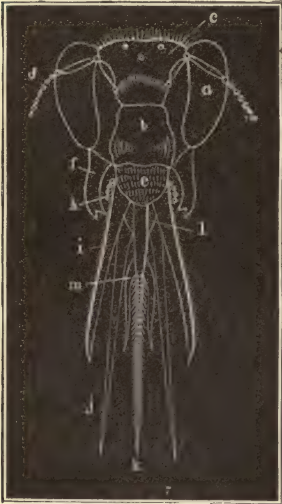


FIG. 220. — Head of a Wild Bee (*Anthophora retusa*), magnified, front view: *a*, compound eyes; *b*, clypeus; *c*, three simple eyes; *d*, antennæ; *e*, labrum; *f*, mandibles; *i*, maxillæ; *h*, maxillary palpi; *l*, palpifer; *j*, labial palpi; *m*, paraglossæ; *k*, ligula.



FIG. 221. — Proboscis of a Butterfly, magnified.

of minute teeth, so as to form a central canal, through which the liquid food is pumped up into the mouth. Seen under

the microscope, the proboscis is made up of innumerable rings interlaced with spiral muscular fibers. The proboscis of the fly is a modified lower lip; that of the bugs and mosquitoes, fitted both for piercing and suction, is formed by the union of four bristles, which are the mandibles and maxillæ strangely altered, and encased in the labium when not in use.

As most of the arachnids live by suction, the jaws are seldom used for mastication. In the scorpion, the apparent representatives of the mandibles of an insect are transformed into a pair of small forceps, and the palpi, so small in insects, are developed into formidable claws: both of these organs are prehensile. In spiders, the so-called mandibles, which move more or less vertically, end in

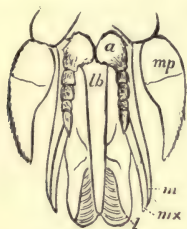


FIG. 222. — Mouth of the Horsefly (*Tabanus lineola*), magnified: *a*, antennæ; *m*, mandibles; *mx*, maxillæ; *mp*, maxillary palpi; *lb*, labrum; *l*, labium, or "tongue."

a fang; and the clublike palpi, often resembling legs, have nothing to do with ingestion or locomotion. Both scorpions and spiders have a soft upper lip, and a groove within the mouth, which serves as a canal while sucking their prey. The tongue is external, and situated between a pair of diminutive maxillæ.

In the ascidians the first part of the alimentary canal is enormously enlarged and modified to serve as a gill sac. At the bottom of this sac, and far removed from

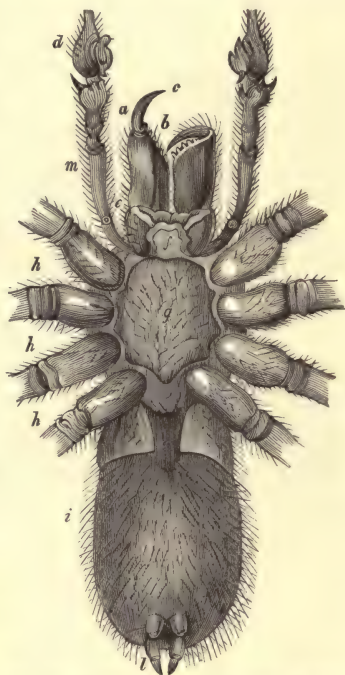


FIG. 223. — Under Surface of Male Spider, enlarged: *a*, *c*, poison fang; *b*, teeth on interior margin of mandible; *e*, *f*, labium; *g*, thorax; *h*, limbs; *i*, abdomen; *l*, spinnerets; *m*, maxillary palpus; *d*, dilated terminal joint.

its external opening, lies the entrance to the digestive tract proper. Into it the particles of food entering with the water are conveyed (Fig. 115).

The mouth of vertebrates is a cavity with a fixed roof (the hard palate) and a movable floor (the tongue and lower jaw), having a transverse opening in front,⁷⁶ and a narrow outlet behind, leading to the gullet. Save in birds and some others, the cavity is closed in front with lips, and the margins of the jaws are set with teeth.

In fishes the mouth is the common entry to both the digestive and respiratory organs; it is, therefore, large, and complicated by a mechanism for regulating the transit of the food to the stomach and the aerated water to the gills. The slits leading to the gills are provided with rows of processes which, like a sieve, prevent the entrance of food, and with valves to keep the water, after it has entered the gills, from returning to the mouth. So that the mouths of fishes may be said to be armed at both ends with teeth-bearing jaws. A few fishes, as the sturgeon, are toothless; but, as a class, they have an extraordinary dental apparatus — not only the upper and lower jaws, but even the palate, tongue, and throat being sometimes studded with teeth. Every part of the mouth is evidently designed for prehension and mastication. Lips are usually present; but the tongue is often absent, or very small, and as often aids respiration as ingestion.

Amphibians and reptiles have a wide mouth; even the insect-feeding toads and the serpents can stretch theirs enormously. True fleshy lips are wanting; hence the savage aspect of the grinning crocodile. With some exceptions, as toads and turtles, the jaws are armed with teeth. Turtles are provided with horny beaks. The tongue is rarely absent, but is generally too thick and short to be of much use. In the toad and frog it

is singularly extensile; rooted in front and free behind, it is shot from the mouth with such rapidity that the insect is seized and swallowed more quickly than the eye can follow. The chameleon's tongue is also extensile. Snakes have a slender forked tongue, consisting of a pair of muscular cylinders, which is solely an instrument of touch.

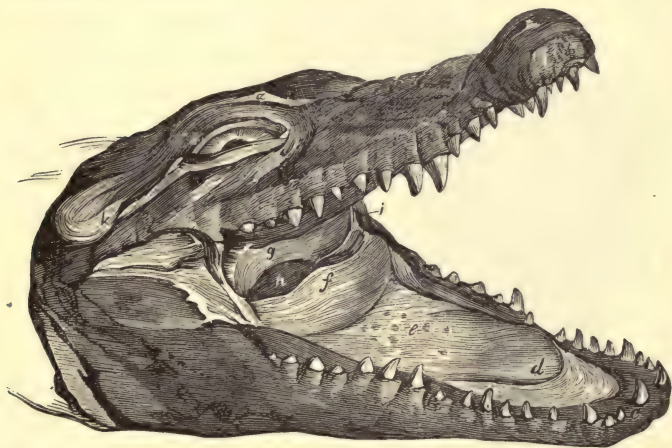


FIG. 224. — Mouth of the Crocodile: *d*, tongue; *e*, glands; *f*, inferior, and *g*, superior, valve, separating the cavity of the mouth from the throat, *h*.

Birds are without lips or teeth, the jaws being covered with horn forming a beak. This varies greatly in shape, being extremely wide in the whip-poor-will, remarkably long in the pelican, stout in the eagle, and slender in the hummer. It is hardest in those that tear or bruise their food, and softest in water birds. The tongue is also covered with a horny sheath, and is generally spinous, its chief function being to secure the food when in the mouth. It is proportionally largest and most fleshy in the parrots.

The main characteristics of the mammalian mouth are flesh lips and mobile cheeks.⁷⁷ In the duck-billed

monotremes lips are wanting, and in the porpoises they are barely represented. But in the herbivorous quadrupeds they, with the tongue, are the chief organs of prehension; in the carnivorous tribes they are thin and retractile; while in the whale the upper lip falls down like a curtain, overlapping the lower jaw several feet. As a rule, the mouth is terminal; but in the elephant,



FIG. 225. — Human Tongue and adjacent parts: *a*, lingual papillæ; *b*, papillæ forming V-shaped lines; *d*, fungiform papillæ; *e*, filiform papillæ; *g*, epiglottis; *m*, uvula, or conical process, hanging from the soft palate, *n*; *o*, hard palate; *r*, palatine glands, the mucous membrane being removed; *v*, section of the lower jaw.

tapir, hog, and shrew, the upper lip blends with the nose to form a proboscis, or snout. The mouth is comparatively small in the elephant and in gnawing animals like the squirrel, wide in the carnivores, short in the sloth, and long in the ant-eater. Teeth are usually present, but vary in form and number with the habits of the animal. The ant-eater is toothless, and the Greenland whale has a sieve made of horny plates. The tongue conforms in size and shape with the lower jaw, and is a muscular, sensitive organ, which serves many purposes, assisting in the prehension, mastication, and swallowing of food,

besides being an organ of taste, touch, and speech. Its surface is covered with minute prominences, called *papillæ*, which are arranged in lines with mathematical precision. In the cats, these are developed into recurved spines, which the animal uses in cleaning bones and combing its fur. Similar papillæ occur on the roof and sides of the mouth of the ox and other ruminants. In some animals, as the hamster and gopher, the cheeks

are developed into pouches in which the food may be carried. These may be lined with hair. The tongue is remarkably long in the ant-eater and giraffe, and almost immovable in the gnawers, elephants, and whales.

3. The Teeth of Animals. — Nearly all animals have certain hard parts within the mouth for the prehension or trituration of

solid food. If these are wanting, the legs are often armed with spines, or pincers, to serve the same purpose, as in the horseshoe crab; or the stomach is lined with

“gastric teeth,” as in some marine snails; or the deficiency is supplied by a muscular gizzard, as in birds,

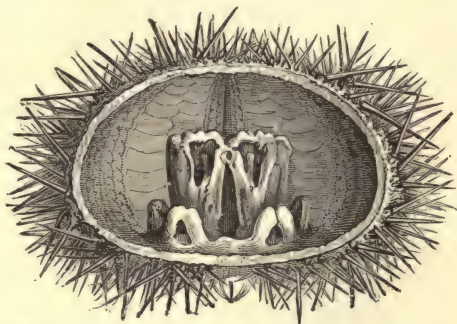


FIG. 226. — Sea Urchin bisected, showing masticating apparatus.

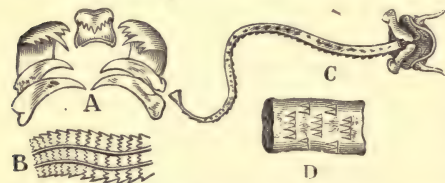


FIG. 227. — Teeth and Masticatory Apparatus of Gastropods, enlarged: A, portion of odontophore, or “tongue,” of *Velutina*, enlarged; B, portion of odontophore of *Buccinum undatum*, magnified — the entire tongue has 100 rows of teeth; C, head and odontophore of *Patella vulgata*; D, portion of same, greatly magnified, to show the transverse rows of siliceous teeth.

ant-eaters, and some insects. Even the lobster and crab, in addition to their complicated oral organs, have the stomach furnished with a powerful set of teeth.

The sea urchin is one of the lowest animals which exhibits anything like a dental apparatus. Five calcareous teeth, having a wedge-shaped apex, each set in a triangular pyramid, or “jaw,” are moved upon each

other by a complex arrangement of levers and muscles. Instead of moving up and down, as in vertebrates, or from right to left, as in arthropods, they converge toward the center, and the food passes between ten grinding surfaces.

The rotifers have a curious pair of horny jaws. That which answers to the lower jaw is fixed, and called the "anvil." The upper jaw consists of two pieces called "hammers," which are sharply notched, and beat upon the "anvil" between them (Fig. 40).

The horny-toothed mandibles of insects, already mentioned, are prehensile, and also serve to divide the food.

The three little white ridges in the mouth of the leech are the convex edges of horny semicircles, each bordered by a row of nearly a hundred hard, sharp teeth. When the mouth, or sucker, is applied to the skin, a sawing movement is given to the horny ridges, so that the "bite" of the leech is really a saw cut.

The dentition of the uni-valve mollusks, or the snails, is generally lingual, *i.e.*, it

consists of microscopic teeth, usually siliceous and amber-colored, planted in rows on the tongue. The teeth are, in fact, the serrated edges of minute plates.

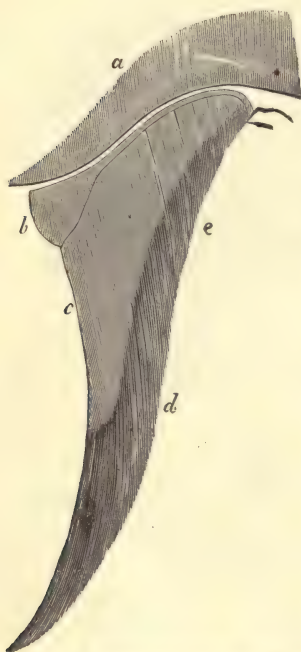


FIG. 228. — Section of one half of the Upper Jaw of a Whale (*Balænoptera*), showing baleen plates: *a*, superior maxillary bone; *b*, ligamentous gum attaching the horny body of the baleen plate, *c*; *d*, fringe of bristles; *e*, smaller plates.

The number of these plates varies greatly ; the garden slug has 160 rows, with 180 teeth in each row.

All living birds, and some other vertebrates, as ant-eaters,⁷⁸ turtles, tortoises, toads, and sturgeons, are without teeth. Their place is often supplied by a horny beak, a muscular gizzard, or both structures.

In a few vertebrates, horny plates take the place of teeth, as the duck mole (*Ornithorhynchus*) and whalebone whale. In the former, the plates consist of closely set vertical hollow tubes; in the latter, the baleen, or whalebone, plates, triangular in shape, and fringed on the inner side, hang in rows from the gums of the upper jaw. In some whales there are about 300 plates on each side.⁷⁹

True teeth, consisting mainly of a hard, calcareous substance called *dentine*, are found only in backboned animals. They are distinct from the skeleton, and differ from bone in containing more mineral matter, and in not showing, under the microscope, any minute cavities, called *lacunæ*. A typical tooth, as found in man, consists of a central mass of *dentine*, capped with *enamel*, and surrounded on the fang with *cement*. The first tissue is always present, while the others may be absent. It is a mixture of animal and mineral matter disposed in the form of extremely fine tubes and cells, so minute as to prevent the admission of the red particles of blood. One modification of it is ivory, seen in the tusks of elephants. Enamel is the hardest tissue of the body, and contains not more than

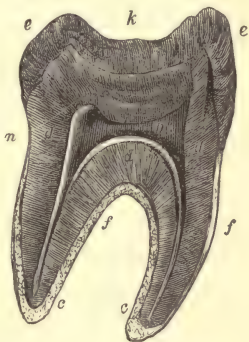


FIG. 229. — Section of Human Molar, enlarged: *k*, crown; *n*, neck; *f*, fang; *e*, enamel; *d*, dentine; *c*, cement; *p*, pulp cavity.

two per cent of animal matter. It consists of six-sided fibers set side by side, at right angles to the surfaces of the dentine. Cement closely resembles bone, and is present in the teeth of only the higher animals.

Teeth are usually confined to the jaws; but the number, size, form, structure, position, and mode of attachment vary with the food and habits of the animal. As a rule, animals developing large numbers of teeth in the back part of the mouth are inferior to those having fewer teeth, and those nearer the lips. The teeth of only mammals have fangs.

The teeth of fishes present the greatest variety. In number, they range from zero to hundreds. The hag-

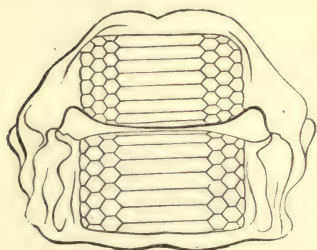


FIG. 230: — Jaws and Pavement teeth of a Ray (*Myliobates*).

fish (*Myxine*) has a single tooth on the roof of the mouth, and two serrated plates on the tongue; while the mouth of the pike is crowded with teeth. In some we find teeth short and blunt, in the shape of cubes, or prisms, arranged like mosaic work. Such pavement

teeth (seen in some rays) are fitted for grinding seaweed and crushing shellfish. But the cone is the most common form: sometimes so slender and close as to resemble plush, as in the perch; or of large size, and flattened like a spearhead with serrated edges, as in the shark; but more often like the canines of mammals, curved inward to fit them for grappling. In the shark, the teeth are confined to the fore part of the mouth; in the carp, they are all situated on the bones of the throat; in the parrot fish, they occupy both back and front; but in most fishes the teeth are developed also on the roof, or palate, and, in fact, on nearly every bone in the mouth. They seldom

appear (as in the salmon) on the upper maxillary. As to mode of attachment, the teeth are generally ankylosed (fastened by bony matter) to the bones which support them, or simply bound by ligaments, as in the shark. In a few fishes, the teeth consist of flexible cartilage; but almost invariably they are composed of some kind of dentine, enamel and cement being absent.

Of amphibians and reptiles, toads, turtles, and tortoises are toothless; frogs have teeth in the upper jaw only; snakes have a more complete set; but saurians possess the most perfect dentition. The number is not fixed even in the same species; in the alligator it varies from 72 to 88. The teeth are limited to the jawbones in the higher forms (saurians); but in others, as the serpents, they are planted also in the roof of the mouth. With few exceptions, they are conical and curved (Fig. 224). In the serpents they are longest and sharpest; and the venomous species have two or more fangs in the upper jaw. These fangs contain a canal, through which the poison is forced by muscles which compress the gland. The bones to which they are attached are movable, and the fangs ordinarily lie flat upon the gums, but are brought into a vertical position in the act of striking. As a rule, the teeth of reptiles are simply soldered to the bone which supports them, or lodged in a groove; but those of crocodiles are set in sockets. Reptilian teeth are made of dentine and a thin layer of cement, to which is added in most saurians a coat of enamel on the crown.

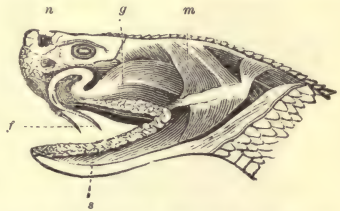


FIG. 231. — Poison Apparatus of the Rattlesnake: *g*, gland, with duct, leading to the fang, *f*; *m*, elevator muscles of the jaw, which, in contracting, compress the gland; *s*, salivary glands on the edge of the jaws; *n*, nostril.

In the majority of mammals, the teeth are limited in number and definite in their forms. The number ranges from 1 in the narwhal (but the longest tooth in the animal kingdom) to 220 in the dolphin. The average is 32, occurring in ruminants, apes, and man; but 44 (as in the hog and mole) is called the typical or normal number, and this number is exceeded only in the lower



FIG. 232. — Skull of the Babirusa, or Malayan Hog, showing growth and curvature of the canines.

groups. When very numerous, the teeth are of the reptilian type, small, pointed, and of nearly equal size, as in the porpoise. In the higher mammals, the teeth are comparatively few, and differ so much in size, shape, and use, that they can be classed into incisors, canines, premolars, and molars. Such a dental series exhibits a double purpose, prehension and mastication. The

chisel-shaped front teeth are fitted for cutting the food, and hence called *incisors*. These vary in number: the lion has six in each jaw; the squirrel has two in each jaw, but remarkably developed; the ox has none in the upper jaw, and the elephant none in the lower; while the sloth has none at all.⁸⁰ The *canines*, so called because so prominent in the dog, are conical, and, except in man, longer than the other teeth. They are designed for seizing and tearing; and they are the most formidable weapons of the wild carnivores. There are never more than four. They are wanting in all rodents, and in nearly all herbivorous quadrupeds. The *molars*, or grinders, vary greatly in shape, but closely correspond with the structure and habits of the animal, so that a single tooth is sufficient to indicate the mode of life and sometimes to identify the species.⁸¹ In the ruminants, rodents, horses, and elephants, the summits of the molars are flat, like millstones, with transverse or curving ridges of enamel. In the cats and dogs, they are narrow and sharp, passing by each other like the blades of scissors, and therefore cutting, rather than grinding, the food. The more purely carnivorous the species, and the more it feeds upon living prey, the fewer the molars. In animals living on mixed diet, as the hog and man, the crowns have blunt tubercles. Premolars, or bicuspid, are those which were preceded by milk teeth; the true, or back, molars had no predecessors.

The dentition of mammals is expressed by a formula, which is a combination of initial letters and figures in fractional form, to show the number and kind of teeth on each side of both jaws. Thus, the formula for man is: $i, \frac{2-2}{2-2}$; $c, \frac{1-1}{1-1}$; $p, \frac{2-2}{2-2}$; $m, \frac{3-3}{3-3} = 32$.

The teeth of mammals are always restricted to the margins of the jaws, and form a single row in each.

But they rarely form an unbroken series.⁸² The teeth implanted in the premaxillary bone, and in the corresponding part of the lower jaw, whatever their number, are incisors. The first tooth behind the premaxillary, if sharp and projecting, is a canine.

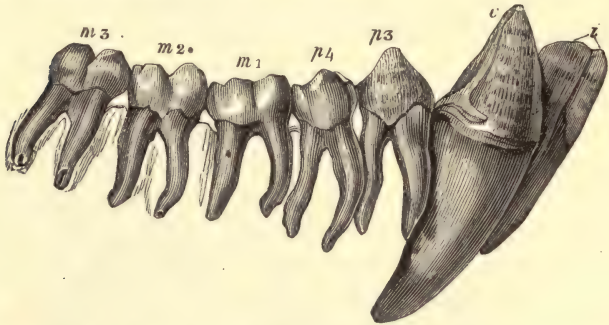


FIG. 233. — Teeth of the right lower jaw of adult male Chimpanzee (*Anthropopithecus troglodytes*), natural size. The molar series does not form a curve, as in Man.

Each tooth has its particular bony socket.⁸³ The molars may be still further strengthened by having two or more diverging fangs, or roots, a feature peculiar to this class. The incisors and canines have but one fang; and those that are perpetually growing, as the incisors of rodents and elephants, have none at all. The teeth of flesh-eating mammals usually consist of hard dentine, surrounded on the root with cement and capped with enamel. In the herbivorous tribes, they are very complex, the enamel and cement being inflected into the dentine, forming folds, as in the molar of the ox, or plates, as in the compound tooth of the elephant. This arrangement of these tissues, which differ in hardness, secures a surface with prominent ridges, well adapted for grinding. The cutting teeth of the rodents consist of dentine, with a plate of enamel on the anterior surface, and the unequal wear preserves a chisel-like edge.

Enamel is sometimes wanting, as in the molars of the sloth and the tusks of the elephant.

In fishes and reptiles, there is an almost unlimited succession of teeth; but mammalian teeth are cast and renewed but once in life.

Vertebrates use their teeth for the prehension of food, as weapons of offense or defense, as aids in locomotion, and as instruments for uprooting or cutting down trees. But in the higher class they are principally adapted for dividing or grinding the food.⁸⁴ While in nearly all

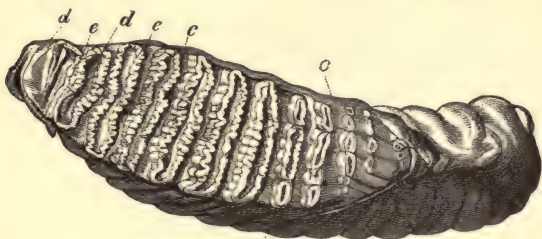


FIG. 234. — Upper Molar Tooth of Indian Elephant (*Elephas indicus*), showing transverse arrangement of dentine, *d*, with festooned border of enamel plates, *e*; *c*, cement; one-third natural size.

other vertebrates the food is bolted entire, mammals masticate it before swallowing. Mastication is more essential in the digestion of vegetable than of animal food; and hence we find the dental apparatus most efficient in the herbivorous quadrupeds. The food is most perfectly reduced by the rodents.

Teeth, as we shall see, are appendages of the skin, not of the skeleton, and, like other superficial organs, are especially liable to be modified in accordance with the habits of the creature. They are, therefore, of great zoölogical value; for such is the harmony between them and their uses, the naturalist can predict the food and general structure of an animal from a sight of the teeth alone. For the same reason, they form important

guides in the classification of animals; while their durability renders them available to the paleontologist in the determination of the nature and affinities of extinct species, of which they are often the sole remains. Even the structure is so peculiar that a fragment will sometimes suffice.

4. Deglutition, or how Animals Swallow. — In the lowest forms of life, the mouth is but an aperture opening immediately into the body substance, and the food is drawn in by ciliary currents (Figs. 9, 11). But in the majority of animals, a muscular tube, called the gullet, or esophagus, intervenes between the mouth and stomach, the circular fibers of which contract, in a wavelike manner, from above downward, propelling the morsel into the stomach.⁸⁵ In the higher mollusks, arthropods, and vertebrates, deglutition is generally assisted by the tongue, which presses the food backward, and by a glairy juice, called saliva, which facilitates its passage through the gullet.⁸⁶ Vertebrates have a cavity behind the mouth, called the *throat*, or *pharynx*, which may be considered as a funnel to the esophagus.⁸⁷ In air breathers, it has openings leading to the windpipe, nose, and ears. In man, as in mammals generally, the process of deglutition is in this wise: the food, masticated by the teeth and lubricated by the saliva, is forced by the tongue and cheeks into the pharynx, the soft palate keeping it out of the nasal aperture, and the valvelike epiglottis falling down to form a bridge over the opening to the windpipe. The moment the pharynx receives the food, it is firmly grasped, and, the muscular fibers contracting above it and left lax below it, it is rapidly thrust into the esophagus. Here, a similar movement (the peristaltic) strips the food into the stomach.⁸⁸ The rapidity of these contractions transmitted along the esophagus may be observed in the neck of a horse while drinking.

Deglutition in the serpents is painfully slow, and somewhat peculiar. For how is an animal, without limbs or molars, to swallow its prey, which is often much larger than its own body? The boa constrictor, *e.g.*, seizes the head of its victim with its sharp, recurving teeth, and crushes the body with its overlapping coils. Then, slowly uncoiling, and covering the carcass

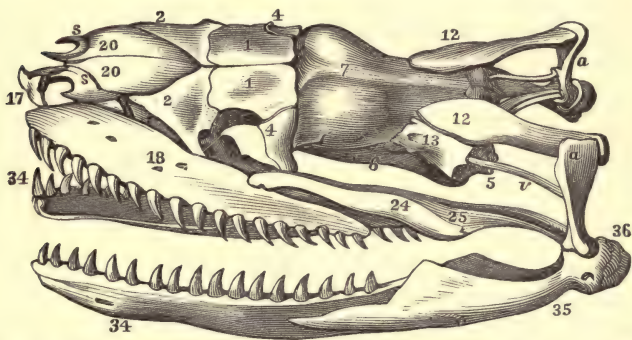


FIG. 235. —Skull of Boa Constrictor: 1, frontal; 2, prefrontal; 4, postfrontal; 5, basi-occipital; 6, sphenoid; 7, parietal; 12, squamosal; 13, proötic; 17, premaxillary; 18, maxillary; 20, nasal; 24, transverse; 25, internal pterygoid; 34, dentary, lower jaw; 35, angular; 36, articular; *a*, quadrate; *s*, prenasal; *v*, petrosal.

with a slimy mucus, it thrusts the head into its mouth by main force, the mouth stretching marvelously, the skull being loosely put together. One jaw is then unfixed, and the teeth withdrawn by being pushed forward, when they are again fastened farther back upon the animal. The other jaw is then protruded and refastened; and thus, by successive movements, the prey is slowly and spirally drawn into the wide gullet.

CHAPTER XII

THE ALIMENTARY CANAL

The Alimentary Canal is the great route by which nutritive matter reaches the interior of the body. It is the most universal organ in the animal kingdom, and the rest are secondary or subservient to it. In the higher animals, it consists of a mouth, pharynx, gullet, stomach, and intestine.

It is a general law, that food can be introduced into the living system only in a fluid state. While plants send forth their roots to seek nourishment from without, animals, which may be likened to plants turned outside in, have their roots (called absorbents) directed inward along the walls of a central tube or cavity. This cavity is for the reception and preparation of the food, so that animals may be said to carry their soil about with them. The necessity for such a cavity arises not only from the fact that the food, which is usually solid, must be dissolved, so as to make its way through the delicate walls of the cavity into the system, but also from the occurrence of intervals between the periods of eating, and the consequent need of a reservoir. For animals, unlike plants, are thrown upon their own wits to procure food.

The Protozoa, as the amœba and Infusoria, can not be said to have a digestive canal. The animal is here composed of a single cell, in which the food is digested. The jellylike amœba passes the food through the firmer outer layer (*ectosarc*) into the more fluid inner part (*endosarc*), where it is digested (Fig. 1). The Infusoria,

which have a cuticle, and so a more definite form, possess a mouth, or opening, into the interior of their cell body, and at least a definite place where the excrement is passed out (Figs. 9, 11). But we can not call this cell cavity a digestive tract.

In the higher animals, the alimentary canal is a continuation of the skin, which is reflected inward, as we turn the finger of a glove.⁸⁹ We find every grade of this reflection, from the sac of the hydra to the long intestinal tube of the ox. So that food in the stomach is still outside of the true body.

The simplest form of such a digestive tract is seen in the hydra (Fig. 18). Here the body is a simple bag,

whose walls are composed of two layers of cells (*ectoderm* and *endoderm*). A mouth leads into the cavity, and serves as well for the outlet of matter not wanted. The endodermal cells furnish the juices by which the food is digested and absorb the nutritious portions of it. The polyps have also

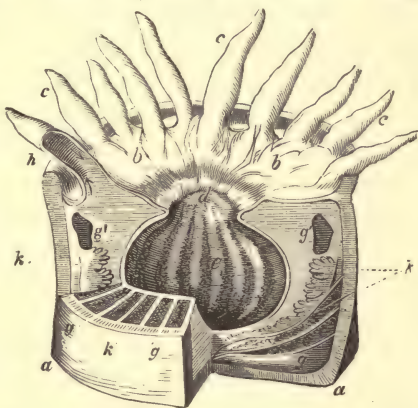


FIG. 236. — Dissected Actinia: *a*, the thick opaque skin consisting of ectoderm, lined with muscular fibers; *c*, the tubular tentacles communicating with the interspaces, *h*, between the membranous vertical folds; *g*, *g'*, orifices in the walls allowing passage of respiratory water from one compartment to another; *d*, mouth leading to gastric cavity, *e*.

but one external opening; but from this hangs down a short tube, open at both ends, reaching about halfway to the bottom of the body cavity. Such an arrangement would be represented by a bottle with its neck turned inward. In this suspended sac, which is somewhat con-

stricted at the extremities, digestion takes place ; but the product passes freely into all the surrounding chambers, along with the water for respiration (Fig. 236). The Medusæ, or jellyfishes, preserve the same type of a digestive apparatus ; but the sac is cut off from the general cavity, and numerous canals radiate from it to a circular canal near the margin of the disk (Fig. 21). In the starfishes (Fig. 323), we find a great advance. The saclike stomach sends off two glandular branches to each arm, which doubtless furnish a fluid to aid in digestion (so-called *hepatic cæca*).^{*} There is also an anus present in some forms, but it hardly serves to pass off the waste matter.

Thus far we have seen but one opening to the digestive cavity, rejected portions returning by the same road by which they enter. But a true alimentary canal should have an anal aperture distinct from the oral. The simplest form of such a canal is exhibited by the sponge, in its system of absorbent pores for the entrance of liquid, and of several main channels for its discharge. The apparatus, however, is not marked off from the general cavity of the body, and digestion is not distinct from circulation.⁹⁰

The sea urchin presents us with an important advance—one cavity with two orifices ; and the complicated apparatus of higher animals is but the development of this type. This alimentary canal begins in a mouth well provided with teeth and muscles, and extends spirally to its outlet, which generally opens on the upper, or opposite, surface. Moreover, while in some of the worms the canal is a simple tube running through the axis of the cylindrical body from oral orifice to anal aperture, the canal of the sea urchin shows a distinction of parts, foreshadowing the pharynx, gullet, stomach, and intestine. Both mouth and vent have muscles for

constriction and expansion; and, as the vent is on the summit of the shell, and the latter is covered with spines, the ejected particles are seized by delicate forks (*pedicellariæ*), and passed on from one to the other down the side of the body, till they are dropped off into the water.⁹¹

The worms present us with a great range of structure in the digestive tract. It is sometimes almost as simple as that of the hydra—a mere sac. The earthworm has a tube running straight through the body, di-

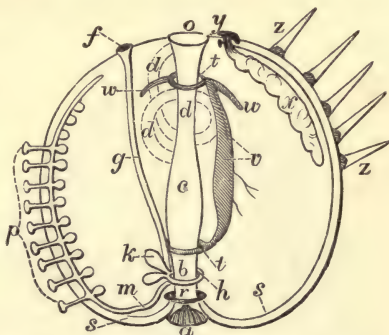


FIG. 237. — Diagrammatic Section of a Sea Urchin (*Echinus*): *a*, mouth; *b*, esophagus; *c*, stomach; *d*, intestine; *f*, madreporiform tubercle; *g*, stone canal; *h*, ambulacral ring; *k*, Polian vesicles, which are probably reservoirs of fluid; *m*, ambulacral tube; *o*, anus; *p*, ambulacra, with their contractile vesicles; *r*, nervous ring around the gullet; *s*, two nervous trunks, the right terminating, at anal pole, in an eye; *t*, blood-vascular rings connected by *v*, the intestinal blood vessel; *w*, two arterial trunks radiating from the anal ring; *x*, an ovary opening at the anal pole in a genital plate; *y*, *z*, spines, with their tubercles.

vided into pharynx, esophagus, crop, gizzard, and sacculated intestine (Fig. 52). The leech has large sacs on each side of the intestine. The sea worms, like *Nereis*, have the pharynx armed with teeth, and some have glandular cœca attached to the intestine. The plan is that of a straight tube extending from mouth to anus. In myriapods and larvæ of insects, the same general plan is continued, the canal passing in a straight line from one extremity to the other, but showing a division into gullet, stomach, and intestine.⁹² Crustacea, like the lobster, have a short gullet leading to a large cavity, situated in the front of the animal, which is a gizzard, rather than stomach, as it has thick muscular walls armed with teeth. A well-marked constriction

separates this organ from the intestine. The "liver," really a pancreas, is highly developed; instead of

numerous follicles, there is a large bilaterally symmetrical organ, divided into three lobes on each side, pouring its secretion into the upper part of the intestine, which is the true stomach.

Among insects, there is great variation in the form and length of the canal. The following parts can generally be distinguished: gullet, crop, gizzard, stomach, and large and small intestines, with many glandular appendages. The crop, gizzard, and large intestine are sometimes absent, especially in the

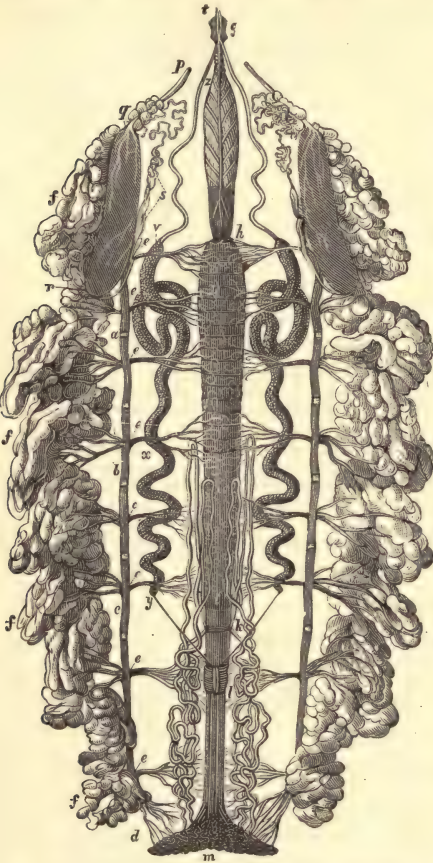


FIG. 238. — Anatomy of a caterpillar: *g, h*, esophagus; *h, i*, stomach; *k*, hepatic vessels; *l, m*, intestine; *q, r*, salivary glands; *p*, salivary duct; *a, b, c*, longitudinal tracheal trunks; *d, e*, air tubes distributed to the viscera; *f*, fat mass; *v, x, y*, silk secretors; *z*, their excretory ducts, terminating in *t*, the spinneret, or *fusulus*.

carnivorous species. In bees, the crop is called the "honey-bag." The gizzard is found in insects having

mandibles, and is frequently lined with rows of horny teeth, which are specially developed in grasshoppers, crickets, and locusts. The intestines are remarkable



FIG. 239. — Alimentary canal of a Beetle: *a*, pharynx; *b*, gullet, leading to crop, *c*, gizzard, *d*, and stomach, *e*; *f*, delicate urinary tubes; *g*, intestine; *h*, other secreting organs.



FIG. 240. — Alimentary Canal of the Bee (*Apis mellifica*): *a*, gullet; *b*, crop; *c*, *d*, stomach; *e*, small intestine; *f*, large intestine; *g*, anal orifice; *h*, urinary vessels; *i*, auxiliary glands.

for their convolutions. Insects have no true liver; but its functions are performed by little cell masses on the inside of the stomach.⁹³

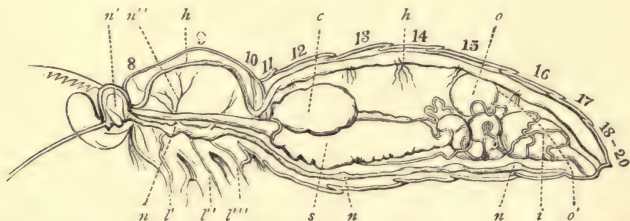


FIG. 241. — Anatomy of a Sphinx Moth: *n*, nervous cord; *n'*, brain sending off nerves to the legs, *l'*, *l''*, *l'''*, and for the wings at *n''*; *h*, dorsal vessel, or heart; *c*, crop; *s*, stomach; *i*, intestines; *o*, reproductive organs; *o'*, oviduct; 8-20, segments.

The alimentary canal of spiders is short and straight, the pharynx and gullet being very minute. The stom-

ach is characterized by sending out tubular prolongations, and the intestine ends in a large bladderlike expansion. Scorpions have no stomachal cavity—a straight intestine passes directly through the body.

In bivalve mollusks, like the clam, the mouth opens into a short esophagus which leads into the stomach,

which lies embedded in a large liver, and the intestine, describing a few turns, passes directly through the heart.⁹⁴ In the univalve mollusks, like the snail, the gullet is long and frequently expands into a crop; the stomach is often double, the anterior being a gizzard provided with teeth for

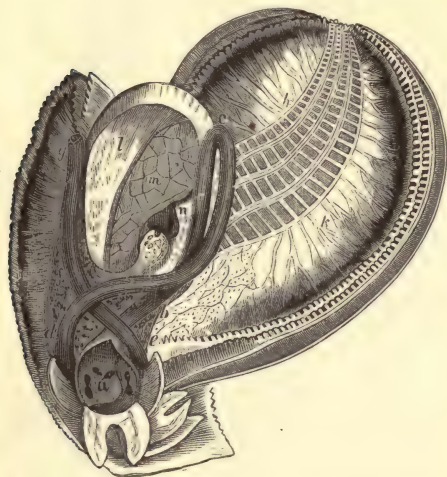


FIG. 242. — Alimentary Canal of the Oyster: *a*, stomach laid open; *d*, liver; *b, c, d, f*, convolutions of the intestine; *g*, anal aperture; *n, o*, auricle and ventricle; *l, m*, adductor muscle; *h, k*, lobes of mouth divided to show the venous canals at the base of the gills.

mastication; the intestine passes through the liver, and ends in the fore part of the body, usually on the right side.

The highest mollusks, as the cuttlefish and nautilus, exhibit a marked advance. A mouth with powerful mandibles leads to a long gullet, which ends in a strong muscular gizzard resembling that of a fowl.⁹⁵ Below this is a cavity, which is either a stomach or duodenum; it receives the secretion from a large digestive gland or pancreas. The intestine is a tube of uniform size, which,



FIG. 243. — Anatomy of a Gastropod (*Snail*): *a*, mouth; *b*, foot; *c*, anus; *d*, lung; *e*, stomach, covered above by the salivary glands; *f*, intestine; *g*, "liver"; *h*, heart; *i*, aorta; *j*, gastric artery; *k*, artery of the foot; *l*, hepatic artery; *m*, abdominal cavity, supplying the place of a venous sinus; *n*, irregular canal communicating with the abdominal cavity, and carrying the blood to the lung; *o*, vessel carrying blood from the lung to the heart.

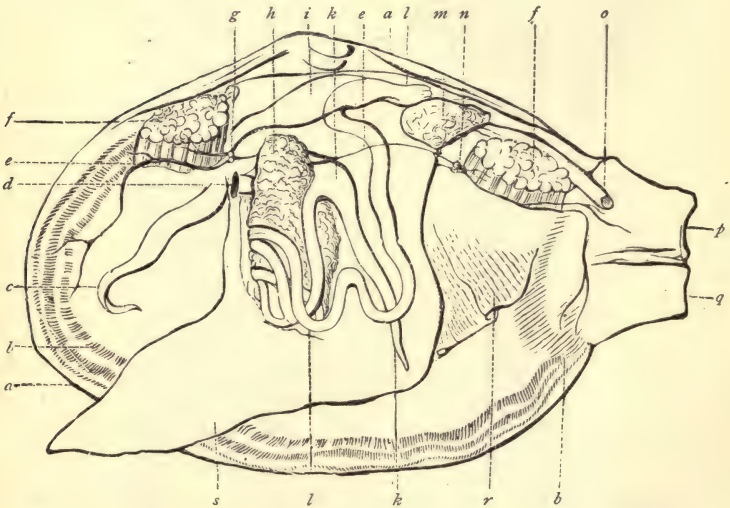


FIG. 244. — Anatomy of a Lamellibranch (*Mactra*): *a*, shell; *b*, mantle; *c*, tentacles, or lips; *d*, mouth; *e*, nerves; *f*, muscles; *g*, anterior, and *n*, posterior ganglion; *h*, "liver"; *i*, heart; *k*, stomach; *l*, intestine passing through the heart; *m*, kidney; *o*, anal end of the intestine; *p*, exhalant, and *q*, inhalant respiratory tubes, or siphons; *r*, gills; *s*, foot.

after one or two slight curves, bends up, and opens into the "funnel" near the mouth.

Fishes have a simple, short, and wide alimentary canal. The stomach is separated from the intestine by a narrow "pyloric" orifice, or valve, but is not so clearly distinguished from the gullet, so that regurgitation is easy.⁹⁶ Indeed, it is common

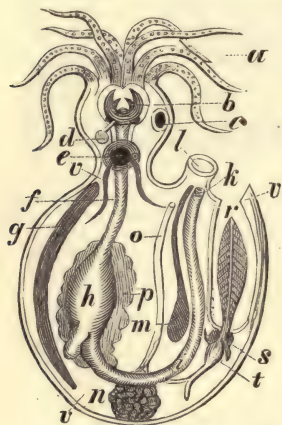


FIG. 245. — Anatomy of a Cephalopod (diagram): *a*, tentacles; *b*, masticatory apparatus; *c*, eye; *d*, salivary gland; *e*, nervous ganglia; *f*, esophagus; *g*, internal shell, or "cuttle-bone"; *h*, stomach; *i*, intestine; *k*, anus; *l*, funnel; *m*, ink bag; *n*, ovary; *o*, oviduct; *p*, "liver"; *r*, gill contained in the branchial chamber; *s*, branchial heart; *t*, systemic heart; *v*, mantle.

for fishes to disgorge the indigestible parts of their food, and some, as the carp, send the food back to the pharynx to be masticated. The stomach is usually bent, like a siphon; but the intestine is nearly straight, and without any marked distinction into small and large. Its appendages are a large liver and a rudimentary pancreas.

In the amphibians, as the frogs, the digestive apparatus is very similar to that of fishes; but the two portions of the intestine can be more readily distinguished. The reptiles generally have a long, wide gullet, which passes insensibly

into the stomach, and a short intestine (about twice the length of the body) very distinctly divided into small and large by a constriction.⁹⁷ The vegetable-feeding tortoises have a comparatively long intestinal tube; and the serpents have a slender stomach, but little wider than the rest of the alimentary canal.

The stomach of the crocodile (Fig. 247) is more complex than any hitherto mentioned. It resembles that of

the cuttlefish, but offers a still more striking analogy to the gizzard of a bird, having very thick walls, and the muscular fibers radiating precisely in the same manner,

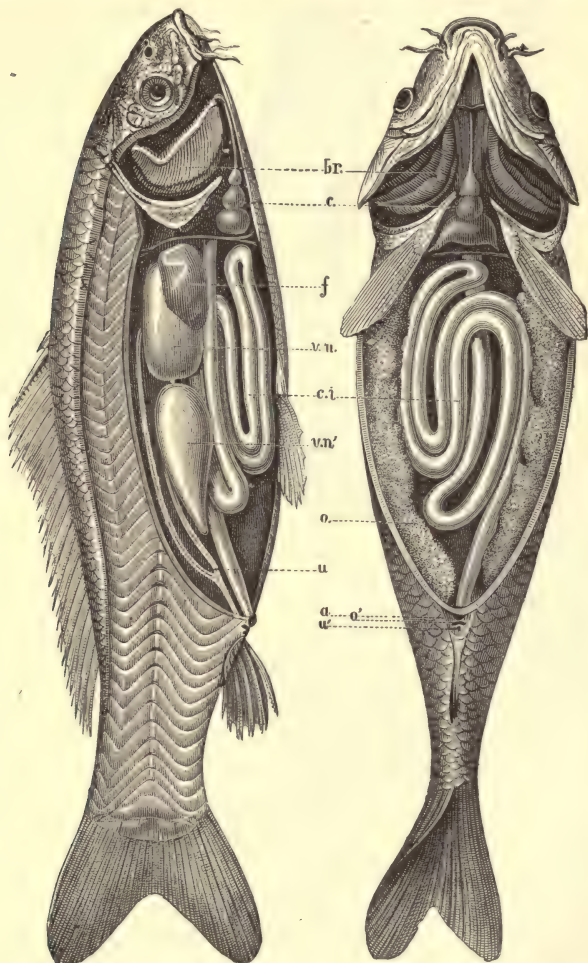


FIG. 246. — Anatomy of the Carp: *br*, branchiæ, or gills; *c*, heart; *f*, liver; *v.n.*, *v.n'*, swimming bladder; *c.i.*, intestinal canal; *o*, ovarium; *u*, ureter; *a*, anus; *o'*, genital opening; *u'*, opening of ureter. The side view shows the disposition of the muscles in vertical flakes.

so that, in this respect, the crocodile may be considered to be intermediate between reptiles and birds.⁹⁸ In



FIG. 247.—Stomach of the Crocodile: *a*, muscular fibers radiating from a central tendon, *b*; *d*, commencement of duodenum; *c*, esophagus; *f*, intestine.

crocodiles also the duodenum, with which the intestine begins, is first distinctly defined. Into this part of the intestine the liver and pancreas, or sweetbread, pour their secretions. Furthermore, in the lower animals, the intestines lie more or less loose in the abdomen; but in the crocodile, and like-

wise in birds and mammals, they are supported by a membrane called *mesentery*.

In birds, the length of the alimentary canal varies with their diet, being greatest in those living on grain and fruit. The gullet corresponds in length with the neck, which is longest in the long-legged tribes, and in width with the food. In those that swallow large fish entire, the gullet is dilatable, as in snakes. In nearly all birds, the food is delayed in some cavity before digestion: thus, the pelican has a bag under the lower jaw, and the cormorant has a capacious gullet, where it stores up fishes; while those that gorge themselves at intervals, as the vulture, or feed on seeds and grains,

as the turkey, have a pouch, called the *crop*, developed near the lower end of the gullet.⁹⁹ The ostrich, goose, swan, most of the waders, and the fruit or insect-eating birds, which find their food in tolerable abundance, and take it in small quantities, have no such reservoir. Pigeons have a double crop.

In all birds, the food passes from the gullet into the *proventriculus*, or stomach proper, where it is mixed with a "gastric juice" secreted from glands on the surface. Thence it goes into the gizzard, an oval sac of highly muscular texture, and lined with a tough, horny skin.¹⁰⁰ The gizzard is most highly developed, and of a deep-red color, in the scratchers and flat-billed swimmers (as fowls and swans); but compara-

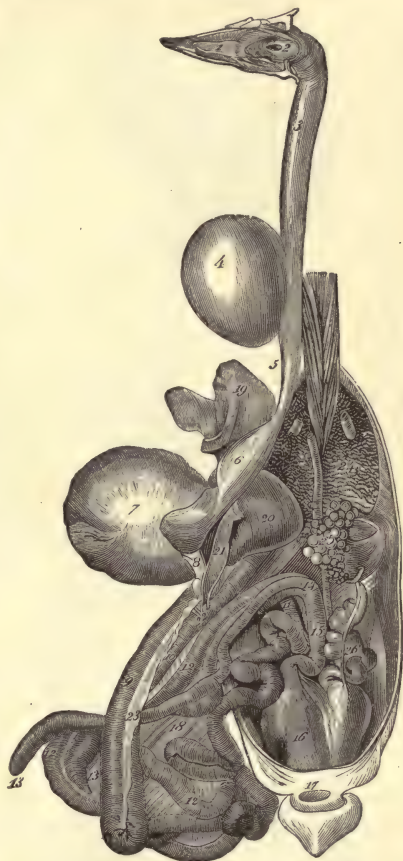


FIG. 248. — Digestive Apparatus of the Fowl: 1, tongue; 2, pharynx; 3, 5, esophagus; 4, crop; 6, proventriculus; 7, gizzard; 8, 9, 10, duodenum; 11, 12, small intestine; 13, two caeca (analogue of the colon of mammals); 14, their insertion into the intestinal tube; 15, rectum; 16, cloaca; 17, anus; 18, mesentery; 19, 20, left and right lobes of liver; 21, gall bladder; 22, insertion of pancreatic and biliary ducts; 23, pancreas; 24, lung; 25, ovary; 26, oviduct.



tively thin and feeble in birds of prey (as the eagle). The gizzard is followed by the intestines, which are longer than those of reptiles: the small intestine begins with a loop (the duodenum), and is folded several times upon itself; the large intestine is short and straight, terminating in the sole outlet of the body, the *cloaca*. A liver and pancreas are always attached to the upper part of the small intestine.

The alimentary canal in mammals is clearly separated into four distinct cavities: the pharynx, or throat; the esophagus, or gullet; the stomach; and the intestines.

The pharynx is more complicated than in birds. It is a funnel-

FIG. 249. — Digestive Apparatus of Man (diagram): 1, tongue; 2, phar-

ynx; 3, esophagus; 4, soft palate; 5, larynx; 6, palate; 7, epiglottis; 8, thyroid cartilage; 9, beginning of spinal marrow; 10, 11, 12, vertebræ, with spinous processes; 13, cardiac orifice of stomach; 14, left end of stomach; 18, pyloric valve; 19, 20, 21, duodenum; 22, gall bladder; 27, duct from pancreas; 28, 29, jejunum of intestine; 30, ileum; 34, cœcum; 36, 37, 38, colon, or large intestine; 40, rectum.

shaped bag, having seven openings leading into it: two from the nostrils, and two from the ears; one from the windpipe, guarded by the epiglottis; one from the mouth, with a fleshy curtain called the *soft palate*; and one from the esophagus. It is the natural passage for food between the mouth and the esophagus, and of air between the nostrils and windpipe. Like the mouth, it is lined with a soft mucous membrane.

The esophagus is a long and narrow tube, formed of two muscular layers: in the outer layer, the fibers run lengthwise; in the other, they are circular. It is lined

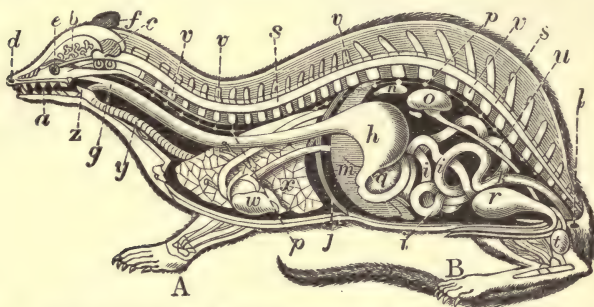


FIG. 250. — Ideal Section of a Mammalian Vertebrate: A, pectoral, or fore limb; B, pelvic, or hind limb; *a*, mouth; *b*, cerebrum; *c*, cerebellum; *d*, nose; *e*, eye; *f*, ear; *g*, esophagus; *h*, stomach; *i*, intestine; *j*, diaphragm, or midriff; *k*, rectum, or termination of intestine; *l*, anus; *m*, liver; *n*, spleen; *o*, kidney; *p*, sympathetic system of nerves; *q*, pancreas; *r*, urinary bladder; *s*, spinal cord; *u*, ureter; *v*, vertebral column; *w*, heart; *x*, lung; *y*, trachea, or windpipe; *z*, epiglottis.

with mucous membrane. While in all fishes, reptiles, and birds the body cavity is one, in mammals it is divided, by a partition called the *diaphragm*, into two cavities, — the thorax, containing the heart, lungs, etc.; and the abdomen, containing the stomach, intestines, etc. The esophagus passes through a slit in the diaphragm, and almost immediately expands into the stomach.

In the majority of mammals, the stomach is a muscular bag of an irregular oval shape, lying obliquely across the abdomen. In the flesh eaters, whose food is easy

of solution, the stomach is usually simple, and lies nearly in the course of the alimentary canal; but in proportion as the food departs more widely in its composition from the body itself, and is therefore more difficult to digest, we find the stomach increasing in size and complexity,

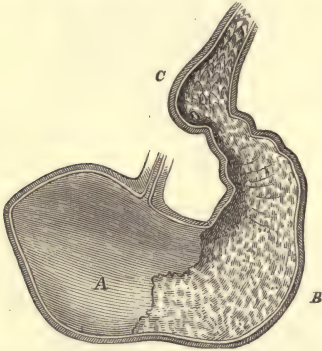


FIG. 251. — Section of Horse's Stomach; A, left sac; B, right sac; C, duodenum.

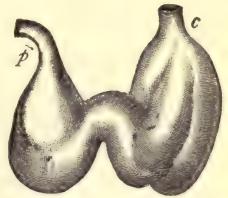


FIG. 252. — Stomach of the Porpoise: c, cardiac opening; p, pyloric opening.

and turned aside from the general course of the canal, so as to retain the food a longer time. The inlet from the esophagus is called *cardiac* opening; the outlet leading into the intestines is called *pyloric* opening.



FIG. 253. — Stomach of the Lion: c, cardiac orifice, or entrance of esophagus; p, pyloric orifice.

In the carnivores, apes, and most odd-toed quadrupeds, the stomach resembles that of man. That of the toothless anteater has the lower part turned into a kind of gizzard for crushing its food,

The elephant's is subdivided by numerous folds. In the horse, it is constricted in the middle; and in the rodents, porpoises, and kangaroos, the constriction is carried so

far as to make two or three sections. But animals that chew the cud (ruminants) have the most complex stomach. It is divided into four peculiar chambers: First, the paunch (*rumen*), the largest of all, receives the half-masticated food when it is first swallowed. The inner surface is covered with papillæ, except in the camel, which has large cells for storing up water. From this, the food passes into the honeycomb stomach (*reticulum*), so named from its structure. Liquids swallowed usually go directly to this cavity, without passing through the paunch, and hence it is sometimes called the water bag. Here the food is made into little balls,

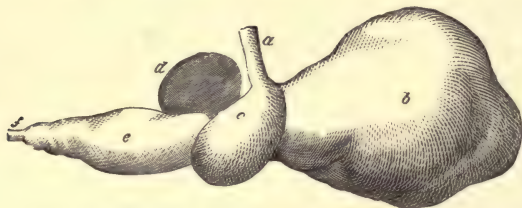


FIG. 254. — Complex Stomach of a Ruminant: *a*, gullet; *b*, rumen, or paunch; *c*, reticulum; *d*, psalterium, or manyplies; *e*, abomasus; *f*, pylorus leading to duodenum.

and returned to the mouth to undergo a thorough mastication. When finally swallowed, it is directed, by a groove from the esophagus, to the third, and smallest, cavity, the manyplies (*psalterium*), named from its numerous folds, which form a strainer to keep back any undivided food; and thence it passes into the true stomach (*abomasus*), from which, in the calf, the rennet is procured for curdling milk in the manufacture of cheese. This fourth cavity is like the human stomach in form and function, and is the only part which secretes gastric juice. The rumen and reticulum are rather dilatations of the esophagus than parts of the stomach itself; while the latter is divided by constriction into two chambers, the psalterium and abomasus, as in many other animals.

In structure the stomach resembles the esophagus. The smooth outside coat (*peritoneum*) is a reflection of the membrane which lines the whole abdomen. The middle, or muscular, coat consists of three layers of fibers, running lengthwise, around and obliquely. The

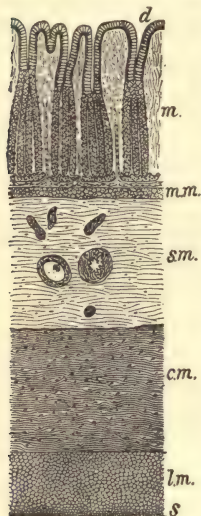


FIG. 255. — Vertical Section of the Coats of the Stomach: *d*, surface of mucous membrane, and mouths of gastric follicles; *m*, gastric tubuli, or follicles; *mm*, dense connective tissue; *sm*, sub-mucous tissue; *cm*, transverse muscular fiber; *lm*, longitudinal muscular fibers; *s*, fibrous, or serous, coat.

successive contraction and relaxing of these fibers produce the worm-like motion of the stomach, called *peristaltic*. The innermost, or mucous, membrane, is soft, velvety, of a reddish gray color in man, and filled with multitudes of glands, which secrete the gastric juice. The human stomach, when distended, will hold about five pints; that of the kangaroo is as long as its body.

The intestinal canal in mammals begins at the pyloric end of the stomach, where there is a kind of valve or circular muscle. Like the stomach, it varies greatly, according to the nature of the food. It is generally longest in the vegetable feeders, and shortest in the flesh feeders. The greater length in the former is due to the fact that vegetable food requires a longer time for digestion, and that a greater bulk of such food is required to obtain a given quantity of nutriment. The intestines measure 150 feet in a full-grown ox, while they are but three times the length of the body in the lion, and six times in man. Save in some lower forms, as the whales, there are two main divisions, the "small" and "large" intestines, at the junction of which is a

valve. The former is the longer of the two, and in it digestion is completed, and from it the most of absorption takes place. The large intestine is mainly a temporary lodging place for the useless part of the food, until it is expelled from the body. The beginning of the small intestine is called the *duodenum*, into which the ducts from the liver and pancreas open. The intestinal canal has the same structure as the stomach, and by a peristaltic motion its contents are propelled downward. The inside of the small intestine is covered with a host of threadlike processes (*villi*), resembling the pile of velvet.

In taking this general survey of the succession of forms which the digestive apparatus presents among the principal groups of animals, we cannot fail to trace a gradual *specialization*. First, a simple sac, one orifice serving as inlet for food and outlet for indigestible matter; next, a short tube, with walls of its own suspended in the body cavity; then a canal passing through the body, and, therefore, having both mouth and vent; next, an apparatus for mastication, and a swelling of the central part of the canal into a stomach, having the special endowment of secreting gastric juice; then a distinction between the small and large intestine, the former thickly set with villi, and receiving the secretions of large glands. We also notice that food, the means of obtaining it, the instruments for mastication, and the size and complexity of the alimentary canal, are closely related.

CHAPTER XIII *

HOW ANIMALS DIGEST

The Object of the Digestive Process is the reduction of food into such a state that it can be absorbed into the system. For this purpose, if solid, it is dissolved; for fluidity is a primary condition, but not the only one. Many soluble substances have to undergo a chemical change before they can form parts of the living body. If albumen or sugar be injected into the veins, it will not be assimilated, but be cast out unaltered.

To produce these two essential changes, solution and transmutation, two agencies are used — one mechanical, the other chemical. The former is not always needed, for many animals find their food already dissolved, as the butterfly; but solid substances, to facilitate their solution, are ground or torn into pieces by teeth, as in man; by jaws, as in the lobster; or by a gizzard, as in the turkey.

The chemical preparation of food is indispensable.¹⁰¹ It is accomplished by one or more solvent fluids secreted in the alimentary canal. The most important, and one always present, is the gastric juice, the secretion of which is restricted to the stomach, when that cavity exists. In the higher animals, numerous glands pour additional fluids into the digestive tube, as saliva into the upper part or mouth, and bile and pancreatic juice into the upper part of the intestine. In fact, the mucous

* See Appendix.

membrane, which lines the alimentary canal throughout, abounds with secreting glands or cells.

The Digestive Process is substantially the same in all animals, but it is carried farther in the more highly developed forms. In the Infusoria, the food is acted upon by some secretion from the protoplasm of the body, the exact nature of which is unknown. In the starfish and sea urchin, we find two solvents — a gastric juice, and another resembling pancreatic juice; but the two appear to mingle in the stomach. Mollusks and arthropods show a clear distinction between the stomach and intestine, and the contents of the pancreas are poured into the latter. There are, therefore, two stages in the digestive act: first, the food is dissolved by the gastric juice in the stomach, forming *chyme*; secondly, the chyme, upon entering the intestine, is changed into *chyle* by the action of the pancreatic secretion, and is then ready to be absorbed into the system.

In vertebrates, a third solvent is added, the bile, which aids the pancreatic juice in completing digestion. But mammals and insects have a still more perfect and elaborate process; for in them the saliva of the mouth acts chemically upon the food; while the saliva in many other animals has no other office, so far as we know, than to moisten the food for swallowing.

Taking man as an example, let us note the main facts in the process. During mastication, by which the relative surface is increased, the food is mixed with saliva, which moistens it,¹⁰² and turns a small part of the starch into grape sugar. Passed into the stomach, the food meets the gastric juice. This is acid, and, first, stops the action of the saliva; secondly, by means of the *pepsin* which it contains, and the acid, it dissolves the albumen, fibrin, and other such constituents of the food. This solution of albuminoids is called a *peptone*,

and is especially distinguished from other such solutions by its diffusibility — *i.e.*, the ease with which it passes through a membrane. Some of these peptones, with the sugars of the food, whether original or the product of the action of the saliva, are absorbed from the stomach. The food, while in the stomach, is kept in continual motion, and, after a time, is discharged in gushes into the intestine. The name *chyme* is given to the pulpy mass of food in the stomach.¹⁰³ In the intestine the chyme meets three fluids — bile, pancreatic juice, and intestinal juice. All of these are alkaline, and at once give the acid chyme an alkaline reaction. This change permits the action of the saliva to recommence, which is aided by the pancreatic and intestinal juices. The pancreatic juice has much more important functions. It changes albuminoid food into peptones, and probably breaks up the fats into very small particles, which are suspended in the fluid chyle. This forms an *emulsion*, like milk, and causes the chyle to appear whitish. The bile has important functions, but little understood. It emulsifies and saponifies part of the fats, so that they are dissolved, and perhaps aids in preventing the food from decomposing during the process of digestion and absorption. The chyle is slowly driven through the small intestine by the creeping, peristaltic motion of its walls,¹⁰⁴ the nutritious portion being taken up by the absorbents, as described in the next chapter, while the undigested part remaining is discharged from the large intestine.¹⁰⁵

CHAPTER XIV

THE ABSORBENT SYSTEM

THE nutritive matter (chyle), prepared by the digestive process, is still outside of the organism. How shall it enter the living tissue?

In animals, like the Infusoria and polyps, whose digestive department is not separated from the body cavity, the food, as soon as dissolved, mingles freely with the parts it has to nourish. In the higher invertebrates having an alimentary canal, the chyle passes, by simple transudation, through the walls of the canal directly into the soft tissues, as in insects, or is absorbed from the canal by veins in contact with it, as in sea urchins, mollusks, worms, and crustaceans, and then distributed through the body.



FIG. 256. — Section of Injected Small Intestine of Cat: *a, b*, mucosa; *g*, villi; *i*, their absorbent vessels; *h*, simple follicles; *c*, muscularis mucosæ; *d*, submucosa; *e, e'*, circular and longitudinal layers of muscle; *f*, fibrous coat. All the dark lines represent blood vessels filled with an injection mass.

In vertebrates only do we find a special absorbent system. Three sets of vessels are concerned in the general process by which fresh material is taken up and added to the blood: **Capillaries**, **Lacteals**, and **Lymphatics**. Only the two former draw material from the alimentary canal.

The food probably is absorbed almost as fast as it is dissolved, and, therefore, there is a constant loss in the passage down the canal. In the mouth and esophagus, the absorption is slight; but much of that which has yielded to the gastric juice, with most of the water, is greedily absorbed by the capillaries of the stomach, and made to join the current of blood which is rushing to the liver. Absorption by the capillaries also takes place from the skin and lungs. Medicinal or poisonous gases and liquids are readily introduced into the system by these channels.

We have seen that the oily part of the food passes unchanged from the stomach into the small intestine,

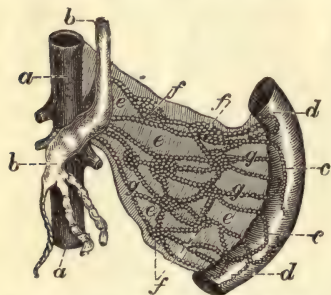


FIG. 257. — Lacteal System of Mammal: *a*, descending aorta, or principal artery; *b*, thoracic duct; *c*, origin of lacteal vessels, *g*, in the walls of the intestine, *d*, mesentery, or membrane attaching the intestine to walls of the body; *f*, lacteal, or mesenteric, glands.

where, acted upon by the pancreatic juice, it is cut up into extremely minute particles, and that the undigested albuminoids and starches are digested in the intestine. Two kinds of absorbents are present in the intestine, lacteals and blood capillaries. Both the lymphatic and blood systems send vessels into the velvety villi¹⁰⁶ with which the intestine is

lined. The blood capillaries lie toward the outside of the villus and the lacteal in the center. The albumi-

noids and sugars are chiefly absorbed by the blood vessels and go to the liver. The fats pass on into the lacteals, which receive their name from the milky appearance of the chyle. These lacteals unite into larger trunks, which lie in the mesentery (or membrane which suspends the intestine from the back wall of the abdomen), and these pour their contents into one large vessel, the *thoracic duct*, lying along the backbone, and joining the jugular vein in the neck.

The lacteals are only a special part of the great lymphatic system, which absorbs and carries to the thoracic duct matter from all parts of the body.¹⁰⁷ The lymph is a transparent fluid having many white blood corpuscles. It is, in fact, blood, minus the red corpuscles, while chyle is the same fluid rendered milky by numerous fat globules. During the intervals of digestion, the lacteals carry ordinary lymph. This fluid is the

overflow of the blood — the plasma and white corpuscles which escape from the blood capillaries, and carry nutriment to, and waste from, those parts of the various tissues which are not in contact with the blood capillaries.

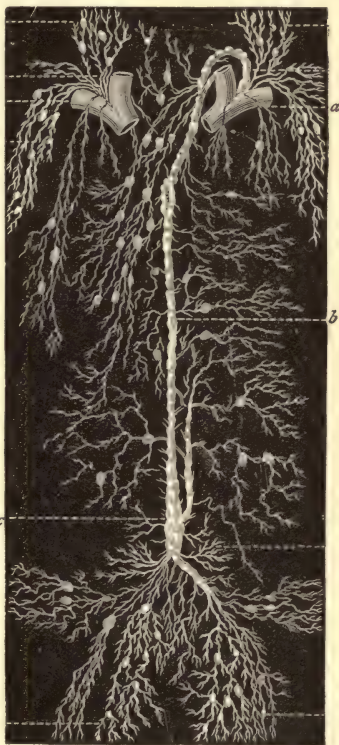


FIG. 258. — Principal Lymphatics of the Human Body: *a*, union of left jugular and subclavian veins; *b*, thoracic duct; *c*, *receptaculum chyli*. The oval bodies are glands.

This surplus overflow is returned to the blood by the lymphatics. The current is kept up by the movements of the body, and in many vertebrates, as frogs and fishes, by *lymph hearts*.

Like the roots of plants, the absorbent vessels do not commence with open mouths ; but the fluid which enters them must traverse the membrane which covers their minute extremities. This membrane is, however, porous, and the fluids pass through it by the processes of filtration and diffusion, or *dialysis*. How the fat gets into the lacteals is not yet well understood, but the lacteals are themselves rhythmically contractile, and force the absorbed chyle toward the heart. The valves of the lymphatics prevent its return.

CHAPTER XV *

THE BLOOD OF ANIMALS

The Blood is that fluid which carries to the living tissues the materials necessary to their growth and repair, and removes their waste and worn-out material. The great bulk of the body is occupied with apparatus for the preparation and circulation of this vital fluid.

The blood of the lower animals (invertebrates) differs so widely from that of man and other vertebrates, that the former were long supposed to be without blood. In them the blood is commonly colorless; but it has a bluish cast in crustaceans; reddish, yellowish, or greenish, in worms; and reddish, greenish, or brownish, in jellyfishes. The red liquid which appears when the head of a fly is crushed is not blood, but comes from the eyes. In vertebrates, the blood is red, excepting the white-blooded, fishlike lancelet *Amphioxus*.¹⁰⁸

As a rule, the more simple the fabric of the body, the more simple the nutritive fluid. In unicellular animals (as Protozoa), in those whose cells are comparatively independent (as sponges), and in small and lowly organized animals (like hydra), there is no special circulating fluid. Each cell feeds itself either directly from particles of food, or from the products of digestion. In polyps and jellyfishes, the blood is scarcely different from the products of digestion, although a few blood corpuscles are present. But in the more highly organized invertebrates the blood is a distinct tissue, coagu-

* See Appendix.

lating, and containing white corpuscles. The blood of the vertebrates, apparently a clear, homogeneous liquid, really consists of minute grains, or globules, of organic matter floating in a fluid. If the blood of a frog be poured on a filter of blotting paper, a transparent fluid (called *plasma*) will pass through, leaving red particles, resembling sand, on the upper surface. Under the microscope, these particles prove to be cells, or flattened disks (called *corpuscles*), containing a nucleus; some are colorless, and others red. In mammals the red disks

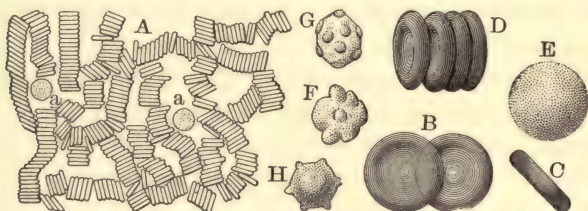
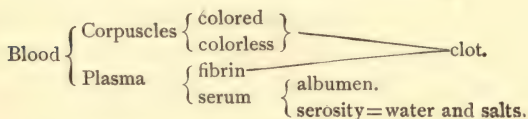


FIG. 259. — Blood Corpuscles: A, red corpuscles in *rouleaux*, *a, a*, colorless corpuscles, magnified about 400 times; B, red corpuscles in focus; C, view of edge; D, three-quarters view; E, red corpuscle swollen with water; F, G, H, distorted red corpuscles.

have a tendency to collect together into piles; the colorless ones remain single. Meanwhile, the plasma separates into two parts by coagulating; that is, minute fibers form, consisting of *fibrin*, leaving a pale yellowish fluid, called *serum*.¹⁰⁹ Had the blood not been filtered, the corpuscles and fibrin would have mingled, forming a jellylike mass, known as *clot*. Further, the serum will coagulate if heated, dividing into hardened albumen and a watery fluid, called *serosity*, which contains the soluble salts of the blood.

These several parts may be expressed thus: —



If now we examine the nutritive fluid of the simplest animals, we find only a watery fluid containing granules. In radiates and the worms and mollusks, there is a similar fluid, with the addition of a few colorless corpuscles. But there is little fibrin, and, therefore, it coagulates feebly or not at all. In the arthropods and higher mollusks, the circulating fluid contains colorless nucleated cells, and coagulates.¹¹⁰ In vertebrates, there are,

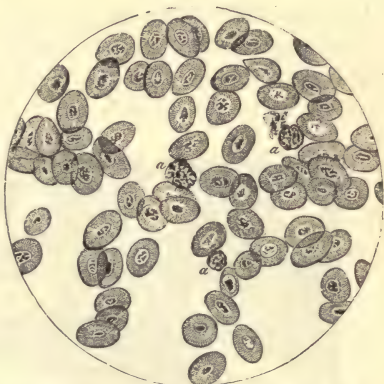


FIG. 260. — Nucleated Blood Cells of a Frog, $\times 250$: a, colorless corpuscles.

in addition to the plasma and colorless corpuscles of invertebrates, red corpuscles, to which their blood owes its peculiar hue. In fishes, amphibians, reptiles, and birds, *i.e.*, all oviparous vertebrates, these red corpuscles are nucleated; but in those of mammals, no nucleus has been discovered.¹¹¹

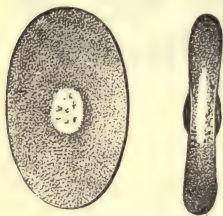


FIG. 261. — Elliptical Corpuscle of the Frog, showing the nucleus as a prominence in the center. Greatly magnified.

All blood corpuscles are microscopic. The colorless are more uniform in size than the red; and generally smaller (except in mammals), being about $\frac{1}{2500}$ of an inch in diameter. The red corpuscles are largest in amphibians (those of *Proteus* being the extreme, or $\frac{1}{250}$ of an inch), next in fishes, then birds and mammals. The smallest known are those of the musk deer. In mammals, the size agrees with the size of the animal

only within a natural order ; but in birds the correspondence holds good throughout the class, the largest being found in the ostrich, and the smallest in the humming bird. In man, they measure $\frac{1}{3200}$ of an inch, so that it would take 40,000 to cover the head of a pin.

As to shape, the colorless corpuscles are ordinarily globular, in all animals ; but they are constantly chang-

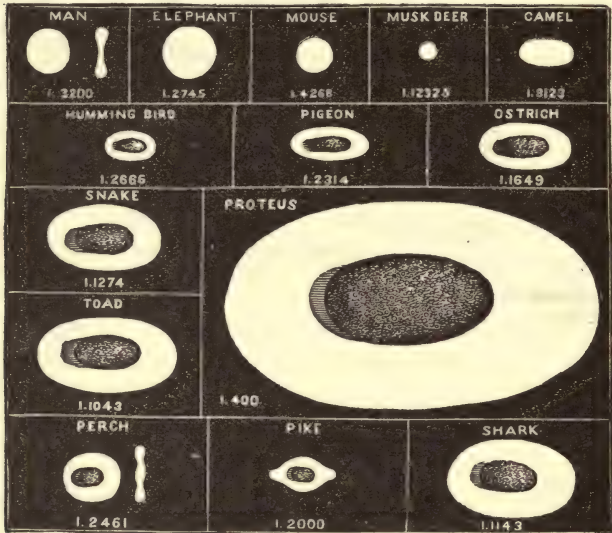


FIG. 262. — Comparative Size and Shape of the red Corpuscles of various Animals.

ing. The form of the red disks is more permanent, although they are soft and elastic, so that they squeeze through very narrow passages. They are oval, circular, or angular, in fishes ; oval in reptiles, birds, and the camel tribe ; and circular in the rest of mammals. They are double convex when nucleated, and double concave when circular and not nucleated.

Blood is always heavier than water ; but is thinner in cold-blooded than in warm-blooded animals, in herbi-

vores than in carnivores. The blood of birds, which is the hottest known, being 104° F. which is 2° – 14° F. higher than mammals', is richest in red corpuscles. In man, they constitute about one half the mass of blood. The white globules are far less numerous than the red; they are relatively more abundant in venous than arte-



FIG. 263. — Capillary Circulation in the Web of a Frog's Foot, $\times 100$: *a*, *b*, small veins; *d*, capillaries in which the oval corpuscles are seen to follow one another in single series; *c*, pigment cells in the skin.

rial blood, in the sickly and ill-fed than in the healthy and vigorous, in the lower vertebrates than in birds and mammals. Their number is subject to great variations, increasing rapidly after a meal, and falling as rapidly.

There is less blood in cold-blooded than in warm-blooded animals; and the larger the animal, the greater is the proportion of blood to the body. Man has about

a gallon and a half, equal to one-thirteenth of his weight. The heart of the Greenland whale is a yard in diameter.

The main **Office of the Blood** is to supply nourishment to, and take away waste matters from, all parts of the body. It is at once purveyor and scavenger. In its circulation, it passes, while in the capillaries, within an infinitesimal distance of the various tissue cells. Some of the plasma, carrying the nutritive matter needed, exudes through the walls of the capillary tubes; the tissue assimilates or makes like to itself whatever is suitable for its growth and repair; and the lymphatics take up the transuded fluid, and return it to the blood vessels. At the same time, the waste products of the tissues are collected and brought through the venous capillaries, veins, and lymphatics to the excretory organs. The special function of the several constituents of the blood is not wholly known. The corpuscles in the red marrow of the bones of some vertebrates are supposed to be the source of the red disks. The latter are the carriers of oxygen which is taken up by their red matter (hemoglobin) in the lungs and given up to the tissues. The same office is performed by the blue coloring matter (hæmocyanin) in the blood of certain invertebrates, as the squid and lobster. The carbon dioxide is taken up mainly by the plasma.

Like the solid tissues, the blood, which is in reality a liquid tissue, is subject to waste and renewal, to growth and decay. The loss is repaired from the products of digestion, carried to the blood by the lacteals, or absorbed directly by the capillaries of the digestive tract. The white corpuscles probably are prepared in many parts of the body, especially the liver, spleen, and lymphatic glands. In the lower organisms, the nutritive food is prepared by contact with the tissues, without

passing through special organs. Lymph differs from blood chiefly in containing less albumen and fibrin, and no red disks. Chyle is lymph loaded with fat globules, and is found in the lacteals and vessels connected with them during the absorption of food containing fat.

CHAPTER XVI *

THE CIRCULATION OF THE BLOOD

The Blood is kept in continual motion in order to nourish and purify the body and itself. For as life

means work, and work brings waste, there is constant need of fresh material to make good the loss throughout the system, and of the removal of matter which is no longer fit for use.

In the very lowest animals, where all parts of the structure are equally capable of absorbing the digested food and are in contact with it, there is no occasion for any circulation, although even in them the digested food is not allowed to stagnate. But in proportion as the power of absorption is confined to certain parts, the more is

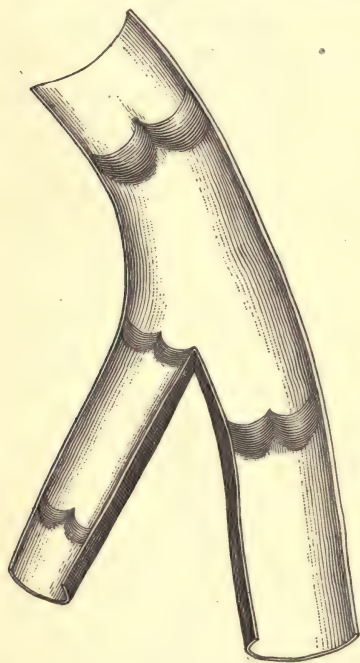


FIG. 264. — Venous Valves. They usually occur in pairs, as represented.

the need and the greater the complexity of an apparatus for conveying the nutritive fluid to the various tissues.

* See Appendix.

In nearly all animals, the nutritive fluid is conveyed to the various parts of the body by a system of tubes, called *blood vessels*. The higher forms have two sets — *arteries* and *veins*, in which the blood moves in opposite directions, the former carrying blood *from* a central reservoir or *heart*, the latter taking it *to* the heart. In the vertebrates the walls of these tubes are made of three coats, or layers, of tissue, the arteries being elastic, like rubber, and many of the veins being furnished with valves.¹¹² The great artery coming out of the heart is called *aorta*, and the grand venous trunk, entering the heart on the opposite side, is called *vena cava*. Both sets divide and subdivide until their branches are finer than hairs; and joining these finest arteries and finest veins are intermediate microscopic tubes, called *capillaries* (in man about $\frac{1}{3000}$ of an inch in diameter).¹¹³ In these only, so thin and delicate are their walls, does the blood come in contact with the tissues or the air.

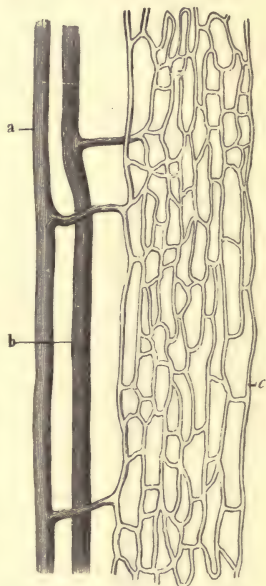


FIG. 265. — Relation of artery, *a*, vein, *b*, and capillaries, *c*, as seen in the muscles of a Dog.

In those vertebrates which have lungs there are two sets of capillaries, since there are two circulations — the *systemic*, from the heart around the system to the heart again, and the *pulmonary*, from the heart through the respiratory organ back to the heart. This double course may be illustrated by the figure 8. In gill-bearing animals there are capillaries in the gills, but not a double circulation.

There is no true system of blood vessels below the echinoderms. The simplest provision for the distribution of the products of digestion is shown by the jelly-fish, whose stomach sends off radiating tubes (Fig. 21), through which the digested food passes directly to the various parts of the body instead of being carried by the agency of a circulating medium — viz., the blood.

The First Approach to a Circulatory System is made by the starfish and the sea urchin. A vein runs along the whole length of the alimentary tube, to absorb the chyle, and forms a circle around each end of the tube. These circular vessels send off branches to various parts of the body; but as they are not connected by a network of capillaries, there can be no circuit (Fig. 237).



FIG. 266. — Part of the Dorsal Vessel, or Heart, of a Cockchafer bisected: *a, b*, muscular walls; *d*, valves between the compartments; *c*, valve defending one of the orifices communicating with the general cavity of the abdomen.

A higher type is exhibited by the insects. If we examine the back of any thin-skinned caterpillar, a long pulsating tube is seen running beneath the skin from one end of the body to the other. This dorsal vessel, or heart, as it is called, is open at both ends, and divided by valves into compartments, permitting the blood to go forward, but not backward. Each compartment communicates by a pair of slits, guarded by valves, with the body cavity, so that fluids may enter, but cannot escape. "Circulation" is very simple. We have seen that the chyle exudes through the walls of the alimentary canal directly

into the cavity of the abdomen, where it mingles with the blood already there. This mixed fluid is drawn

into the dorsal tube through the valvular openings as it expands; and upon its contraction, all the side valves are closed, and the fluid is forced toward the head. Passing out at the front opening, it is again diffused among and between the tissues of the body. The blood, therefore, does not describe a circle in definite channels so as to return constantly to its point of departure.

Many worms (as the earthworm) have a pulsating tube extending from tail to head above the alimentary canal, a similar tube on the ventral side through which

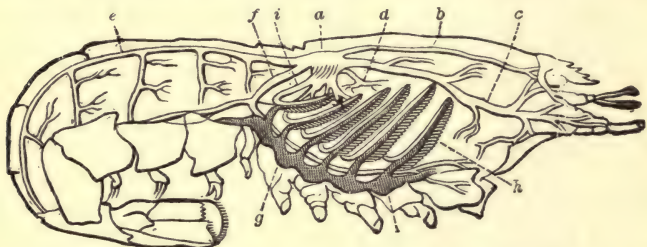


FIG. 267. — Circulation in a Lobster: *a*, heart; *b*, artery for the eyes; *c*, artery for antennæ; *d*, hepatic artery; *e*, superior abdominal artery; *f*, sternal artery; *g*, venous sinuses transmitting blood from the body to the branchiæ, *h*, whence it returns to the heart by the branchio-cardiac vessels, *i*.

the blood returns, and cross tubes in every segment (Fig. 52). In the lobster and crab, spider and scorpion, the dorsal tube sends off a system of arteries (not found in insects); but the blood, as it leaves these tubes, escapes into the general cavity, as in other Arthropoda. The lobster and crab, however, show a great advance in the concentration of the propelling power into a short muscular sac.

A third development of the circulatory system is furnished by the mollusks. Comparatively sluggish, they need a powerful force pump in the form of a compact heart. In the oyster and snail (Figs. 242, 243), we find such an organ having two cavities — an auricle

and a ventricle, one for receiving, and the other for distributing, the blood. The auricle injects the blood into the ventricle, which propels it by the arteries to the various organs. Thence it passes not immediately

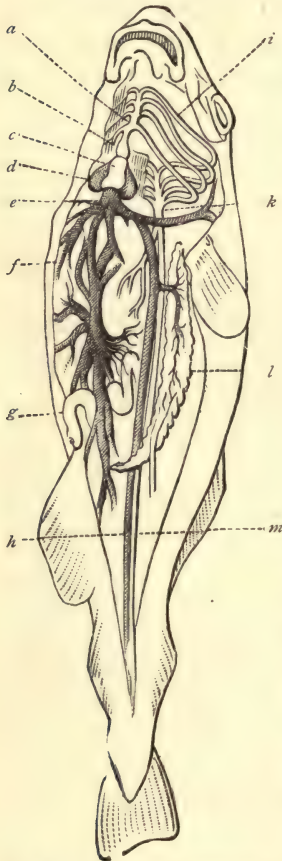


FIG. 268. — Circulating Apparatus in the Fish: *a*, branchial artery; *b*, arterial bulb; *c*, ventricle; *d*, auricle; *e*, venous sinus; *f*, portal vein; *g*, intestine; *h*, vena cava; *i*, branchial vessels; *k*, dorsal artery, or aorta; *l*, kidneys; *m*, dorsal artery.

to the veins, as in higher animals, but into the spaces around the alimentary canal. A part of this is carried by vessels to the gills or lung, and then returned with the unpurified portion to the auricle. The whole of the blood, therefore, does not make a complete circuit. The clam has a similar heart, but with two auricles.

A still higher form is seen in the cuttlefish, the highest of the invertebrates. This animal has a central heart, with a ventricle and two auricles, and, in addition, the veins which collect the blood from the system to send it back to the heart by the way of the gills are furnished with two *branchial hearts*, which accelerate the circulation through those organs. Many of the arteries and veins are joined by capillaries, but not all; so that in no invertebrate animal is the blood returned to the heart by a continuous closed system of blood vessels.

As a rule, in all animals having any circulation at all, the current always takes one direction. This is generally necessitated by valves. But a curious exception is presented by the ascidians, whose tubular heart is valveless, and the contractions occur alternately at one end and then the other; so that the blood oscillates to and fro, and a given vessel is at one time a vein and at another an artery. In this respect it resembles the foetal heart of higher animals (Fig. 364).

In vertebrates only is the circulating current strictly confined to the blood vessels; in no case does it escape into the general cavity of the body. In other respects, there is no great advance in the apparatus of the lowest vertebrates over that of the highest mollusks. A fish's heart has, like that of an oyster, two cavities, but its position is reversed. Instead of driving arterial blood over the body, it receives the returning, or venous, blood, and sends it to the gills. Recollected from the gills, the blood is passed into a large artery, or *aorta*, along the back, which distributes it by a complex system of capillaries among the tissues. These capillaries unite with the ends of the veins which pass the blood into the auricle¹¹⁴ (Figs. 268, 272).

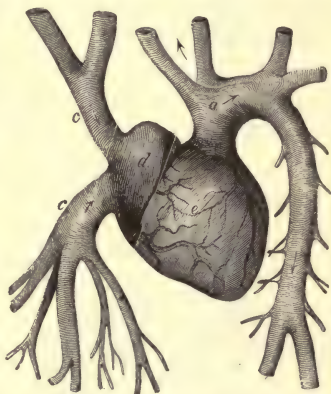


FIG. 269. — Diagram of a Single Heart: *a*, auricle; *e*, ventricle; *c*, veins leading to auricle; *a*, aorta, or main artery.

In amphibians and in reptiles generally (as frogs, snakes, lizards, and turtles), the heart has three cavities — two auricles and one ventricle. The venous blood from the body is received into the right auricle, and the

purified blood from the lungs into the left. Both throw their contents into the ventricle, which pumps the mixed blood in two directions — partly to the lungs, and partly around the system (Fig. 273). Circulation is, therefore, incomplete, since the whole current does not pass through the lungs, and three kinds of blood are found in the body — arterial, venous, and mixed. In many animals, however, arrangements exist which nearly separate the venous from the arterial blood.

The ventricle of reptiles is partially divided by a partition. In the crocodile, the division is complete, so that there are really four cavities — two auricles, and two ventricles. But both ventricles send off aortas which cross one another, and at that point a small aperture brings the two into communication. The venous and arterial currents are, therefore, mixed, but not within the heart, as in other reptiles, nor so extensively. In

the structure of the heart, as well as in that of the gizzard, crocodiles approach the birds.

The Highest Form of the Circulating System is possessed by the warm-blooded vertebrates, birds and mammals. Not a drop of blood can make the circuit of the body without passing through the lungs, the circulation to and from those organs being as perfect as the distribution of arterial

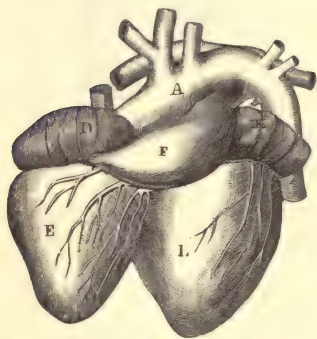


FIG. 270. — Heart of the Dugong, a four-chambered heart, the parts being more separated than in higher animals: E, right ventricle; L, left ventricle; D, right auricle; F, pulmonary artery; K, left auricle; A, aorta.

blood. The heart consists of four cavities — a right auricle and ventricle, and a left auricle and ventricle. In other words, it is a hollow muscle divided internally

by a vertical partition into two distinct chambers, each of which is again divided by a valve into an auricle and a ventricle. The work of the right auricle and ventricle is to receive the blood from the veins, and send it to the lungs; while the other two receive the blood from the lungs, and propel it over the body. The left ventricle has more work to do than any of

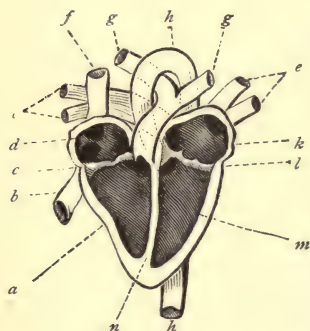


FIG. 271. — Theoretical Section of the Human Heart: *a*, right ventricle; *b*, inferior vena cava; *c*, tricuspid valve; *d*, right auricle; *e*, pulmonary veins; *f*, superior vena cava; *g*, pulmonary arteries; *h*, aorta; *k*, left auricle; *l*, mitral valve; *m*, left ventricle; *n*, septum.

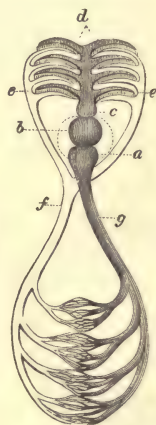


FIG. 272. — Plan of Circulation in Fishes: *a*, auricle; *b*, ventricle; *c*, branchial artery; *e*, branchial veins, bringing blood from the gills, *d*, and uniting in the aorta, *f*; *g*, vena cava.

the other parts of the heart. The two auricles contract at the same instant; so also do the ventricles. The course of the current in birds and mammals is as follows: the venous blood brought from the system is discharged by two or three large trunks¹¹⁵ into the right auricle, which immediately forces it past a valve¹¹⁶ into the right ventricle. The ventricle then contracts, and the blood is forced through the pulmonary artery past its semilunar valves into the lungs, where it is changed

from venous to arterial, returning by the pulmonary veins to the left auricle. This sends it past the mitral valves into the left ventricle, which drives it past the semilunar valves into the aorta, and thence, by its ramifying arteries and capillaries, into all parts of the body except the lungs. From the systemic capillaries, the blood, now changed from arterial to venous, is gathered by the veins, and conveyed back to the heart.

The Rate of the Blood Current generally increases with the activity of the animal, being most rapid in birds.¹¹⁷

In insects, however, it is comparatively slow; but this is because the air is taken to the blood — the whole body being bathed in air, so that the blood has no need to hasten to a special organ. However, activity nearly doubles the rate of pulsation in a bee. The motion in the arteries is several times faster than in the veins, but diminishes as

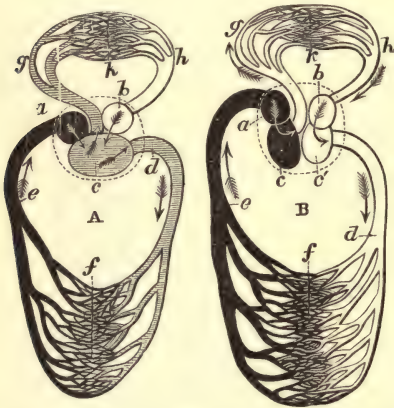


FIG 273. — A, Plan of Circulation in Amphibia and Reptiles; B, Plan of Circulation in Birds and Mammals: *a*, right auricle receiving venous blood from the system; *b*, left auricle receiving arterial blood from the lungs; *c*, *c'*, ventricles; *d*, *e*, *f*, systemic artery, vein, and capillaries; *g*, pulmonary artery; *h*, *k*, vein and capillaries.

the distance from the heart increases. In the carotid of the horse, the blood moves $12\frac{1}{2}$ inches per second; in that of man, 16; in the capillaries of man, 1 to 2 inches per minute; in those of a frog, 1.

The Cause of the Blood Current may be cilia, or the contractions of the body, or pulsating tubes or hearts. In the higher animals, the impulse of the heart is not the

sole means : it is aided by the contractions of the elastic walls of the arteries themselves, the movements of the chest in respiration, and the attraction of the tissues for the arterial blood in the capillaries. In the chick, the blood moves before the heart begins to beat ; and if the heart of an animal be suddenly taken out, the motion in the capillaries will continue as before. It has been estimated that the force which the human heart expends in twenty-four hours is about equivalent to lifting 217 tons one foot.

CHAPTER XVII *

HOW ANIMALS BREATHE

Arterial Blood, in passing through the system, both loses and gains certain substances. It loses constructive material and oxygen to the tissues. These losses are made good from the digestive tract and breathing organ. It gains also certain waste materials from the tissues, which must be got rid of. Of these waste products, one, carbon dioxide, is gaseous, and is passed off from the same organ as that where the oxygen is taken in. This exchange of gases between the animal and its surroundings is called *respiration*.

The First Object of Respiration is to convert venous into arterial blood. It is done by bringing it to the surface, so that carbon dioxide may be exhaled and oxygen absorbed. The apparatus for this purpose is analogous to the one used for circulation. In the lowest animals, the two are combined. But in the highest, each is essentially a pump, distributing a fluid (in one case air, in the other blood) through a series of tubes to a system of cells or capillaries. They are also closely related to each other: the more perfect the circulation, the more careful the provision made for respiration.

Respiration is performed either in air or in water. So that all animals may be classed as *air breathers* or *water breathers*. The latter are, of course, aquatic, and seek the air which is dissolved in the water. Land snails, myriapods, spiders, insects, reptiles, birds, and mam-

* See Appendix.

mals breathe air directly; the rest, with few exceptions, receive it through the medium of water. In the former case, the organ is internal; in the latter, it is more or less on the outside. But however varied the organs — tubes, gills, or lungs — they are all constructed on the same principle — a thin membrane separating the blood from the atmosphere.

(1) **Protozoa, Sponges, and Polyps** have no separate respiratory apparatus, but absorb air, as well as food, from the currents of water passing through them or bathing the surface of their bodies.

In the starfish, sea urchin, and the like, we find the first distinct respiratory organs, although none are exclusively devoted to respiration. There are two sets of canals — one carrying the nutrient fluid, and the other, radiating from a ring around the mouth, distributing aerated water, used for locomotion as well as respiration. This may be called the “water-pipe system.” Besides this, there are sometimes numerous gill-like fringes, which cover the surface of the body and probably aid in respiration.

Freshwater worms, like the leech and earthworm, breathe by the skin. The body is always covered by a viscid fluid, which has the property of absorbing air.

The air is therefore brought into immediate contact with the soft skin, underneath which lies a dense network of blood vessels.

But most water-breathing animals have gills. The simplest form is seen in marine worms: delicate veins projecting through the skin make a series of arborescent



FIG. 274. — Lobworm (*Arenicola piscatorum*), a dorsibranchiate, showing the tufts of capillaries, or external gills. The large head is without eyes or jaws.

tufts along the side of the body; as these float in the water, the blood is purified.¹¹⁸ Bivalve mollusks have four flat gills, consisting of delicate membranes filled with blood vessels and covered with cilia. In the oyster, these ribbonlike folds are exposed to the water when the shell opens; but in the clam, the mantle incloses them, forming a tube, called *siphon*, through which the water is driven by the cilia. The aquatic

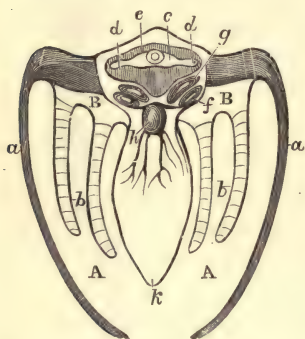


FIG. 275. — Diagrammatic Section of a Lamellibranch (*Anodonta*): *a*, lobes of mantle; *b*, gills, showing transverse partitions; *c*, ventricle of heart; *d*, auricles; *e*, pericardium; *f*, *g*, kidneys; *h*, venous sinus; *k*, foot; *A*, branchial, or pallial, chamber; *B*, epibranchial chamber.

gastropods (univalves) have either tufts, like the worms, or comblike ciliated gills in a cavity behind the head, to which the water is admitted through an opening. In others the breathing organ is the vascular lining of this cavity. The cuttlefish has flat gills covered by the mantle; but the water is drawn in by muscular contractions of the mantle instead of by cilia. The end of the siphon through which it is ejected is called the *funnel*. The gills of lobsters and crabs are

placed in cavities covered by the sides of the shell (carapace); and the water is brought in from behind by the action of a scoop-shaped process attached to one of the jaws, which constantly bails the water out at the front.

The perfection of apparatus for aquatic respiration is seen in fishes. The gills are comblike fringes supported on four or five bony or cartilaginous arches, and contain myriads of microscopic capillaries, the object being to expose the venous blood in a state of minute subdivision

to streams of water. The gills are always covered. In bony fishes they are attached to the hinder side of bony arches, all covered by a flap of the skin, supported by bones (the gill cover, or *operculum*), and the water escapes from the opening left at its hinder edge. In sharks, the gills are placed in pouches which open separately (Figs. 122, 360). The act of "breathing water" resembles swallowing, only the water passes over the surface of the gills instead of entering the gullet.



FIG. 276. — Spiracle of an Insect, $\times 75$.

(2) **Air Breathers** have *tracheæ*, or *lungs*. The former consist of two principal tubes, which pass from one end of the body to the other, opening on the surface by apertures, called *spiracles*, resembling a row of buttonholes along the sides of the thorax and abdomen, and ramifying through the smallest and most delicate organs, so that the air may follow the blood wherever it circulates. To keep the pipes ever open, and at the same time leave them flexible, they are provided inside with an elastic spiral thread, like the rubber tube of a droplight.



FIG. 277. — Tracheal Tube of an Insect, highly magnified, showing elastic spiral thread.

Respiration is performed by the movements of the abdomen, as may be seen in the bee when at rest. This "air-pipe system," as it may be termed, is best developed in insects.

The “nerves” of an insect’s wing consist of a tube within a tube, the inner one is a trachea carrying air, and the outer one, sheathing it, is a blood vessel. So

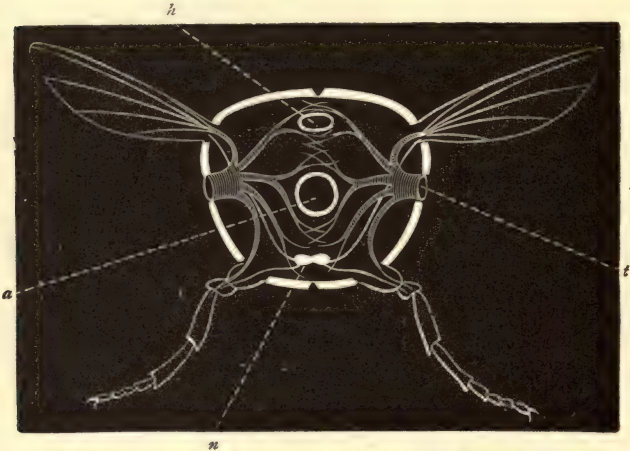


FIG. 278. — Ideal Section of a Bee: *a*, alimentary canal; *h*, dorsal vessel; *t*, trachea; *n*, nervous cord.

perfect is the aëration of the whole body, from brain to feet, the blood is oxygenated at the moment when, and on the spot where, it is carbonized; only one kind of fluid is, therefore, circulating — arterial. It is difficult to drown an insect, as the water can not enter the pores; but if a drop of oil be applied to the abdomen, it falls dead at once, being suffocated. The largest spiracle is usually found on the thorax, as under the wing of a moth; such may be strangled by pinching the thorax.

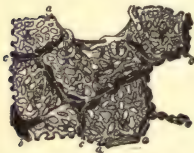


FIG. 279. — Section of injected Lung (highly magnified): *a*, *a*, free edges of alveoli; *c*, *c*, partitions between neighboring alveoli; *b*, small arterial branch giving off capillaries to the alveoli.

In millepedes and centipedes, the spiracles open into little sacs connected together by tubes; in spiders and scorpions, the

spiracles, usually four in number, are the mouths of sacs without the tubes, and the interior of the sac is gathered into folds. Land snails have one spiracle, or aperture, on the right side of the neck, leading to a large cavity, or sac, lined with fine blood vessels. These sacs represent the primitive idea of a lung, which is but an infolding of the skin, divided up into cells, and covered with capillary veins.¹¹⁹



FIG. 280. — Part of a Transverse Section of a Pig's Bronchial Twig, $\times 240$: *a*, outer fibrous layer; *b*, muscular layer; *c*, inner fibrous layer; *d*, epithelial layer with cilia; *f*, one of the neighboring alveoli.

Like the alimentary canal, the lungs of an animal are really an inflected portion of the outer surface; so that breathing by the skin and breathing by lungs are one in principle. Indeed, in many animals, especially frogs, respiration is carried on by both lungs and skin.

In the course of embryonic development the lungs of vertebrates are derived from the front part of the alimentary canal. In some fishes, air is swallowed, which passes the whole length of the digestive tract, and is expelled from the anus. Here the whole canal serves for respiration. In reptiles, birds,

and mammals the hinder part of the intestine develops an outgrowth (the *allantois*) during embryo life which serves as the embryo's breathing organ (Figs. 365, 366).



FIG. 281. — Lungs of a Snake: *a*, trachea; *b*, its bifurcation; *c*, pulmonary artery; *d*, pulmonary vein; the lung, *B*, is rudimentary.

All vertebrates have two kinds of respiratory organs in the course of their life. Fishes have gills; their lung (the air bladder) rarely serves as a functional respiratory organ, and is sometimes wanting. Amphibians have gills while in the larval state. Some keep them throughout life; but all develop functional lungs, and also breathe by means of the skin.

In the remaining vertebrates, the allantois is the breathing organ of the embryo, and the lung is the breathing organ of the adult. The skin is of small or no importance in respiration.

The lungs of vertebrates are elastic, membranous sacs, divided more or less into cavities (the *air cells*) to increase the surface. Upon the walls of the air cells are spread the capillary blood vessels. The smaller the cells, the greater the extent of surface upon which the blood is exposed to the influence of the air, and, therefore, the more active the respiration, and the purer the blood. The lungs are relatively largest in reptiles, and smallest in mammals. But in the cold-blooded amphibians and reptiles, the air cells are

few and large; in the warm-blooded birds and mammals, they are exceedingly numerous and minute.¹²⁰ Respiration is most perfect in birds; they require, relatively to their weights, more air than mammals or reptiles, and

most quickly die for lack of it. In birds, respiration is not confined to the lungs; but, as in insects, extends through a great part of the body. Air sacs connected with the lungs exist in the abdomen and under the skin of the neck, wings, and legs. Even the bones are hollow for this purpose; so that if the windpipe be

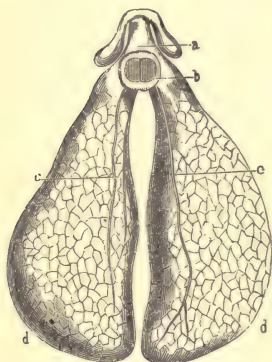


FIG. 282. — Lungs of a Frog; *a*, hyoid apparatus; *b*, cartilaginous ring at root of the lungs; *c*, pulmonary vessels; *d*, pulmonary sacs, having this peculiarity common to all cold-blooded air breathers, that the trachea does not divide into bronchial branches, but terminates abruptly by orifices which open at once into the general cavity. A cartilaginous network divides the space into little sacs, on the walls of which the capillaries are spread.

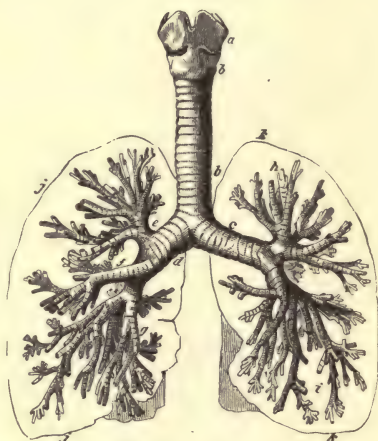


FIG. 283. — Distribution of Air Tubes in Mammalian Lungs: *a*, larynx; *b*, trachea; *c*, *d*, left and right bronchial tubes; *e*, *f*, *g*, the ramifications. In Man the subdivision continues until the ultimate tubes are one twenty-fifth of an inch in diameter. Each lobule represents in miniature the structure of the entire lung of a Frog.

tied, and an opening be made in the wing bone, the bird will continue to respire. The right lung is usually the larger; in some snakes, the left is wanting entirely. In most vertebrates, lungs are freely suspended; in birds, they are fastened to the back.

The lungs communicate with the atmosphere by means of the *trachea*, or windpipe, formed of a series of cartilaginous rings, which keep it constantly open. It

begins in the back part of the mouth, opening into the pharynx by a slit, called the *glottis*, which, in mammals, is protected by the valvelike *epiglottis*. The trachea passes along the neck in front of the esophagus, and divides into two branches, or *bronchi*, one for each lung. In birds and mammals, the bronchial tubes, after entering the lungs, subdivide again into minute ramifications.

Vertebrates are the only animals that breathe through the mouth or nostrils. Frogs, having no ribs, and turtles, whose ribs are soldered together into a shield,

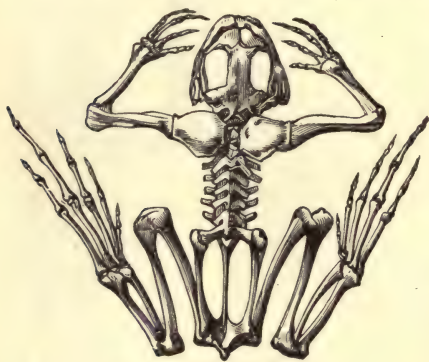


FIG. 284. — Skeleton of a Frog.

are compelled to swallow the air. Snakes, lizards, and crocodiles draw it into the lungs by the play of the ribs.¹²¹ Birds, unlike other animals, do not inhale the air by an active effort; for that is done by the springing back

of the breastbone and ribs to their natural position. To expel the air, the breastbone is drawn down toward the backbone by muscles, which movement compresses the lungs.

Mammals alone have a perfect thorax — *i.e.*, a closed cavity for the heart and lungs, with movable walls (breastbone and ribs) and the *diaphragm*, or muscular partition, separating it from the abdomen.¹²² Inspiration (or filling the lungs) and expiration (or emptying the lungs) are both accomplished by muscular exertion; the former, by raising the ribs and lowering the diaphragm, thus enlarging the capacity of the chest, in

consequence of which the air rushes in to prevent a vacuum; the latter, by the ascent of the diaphragm and the descent of the ribs.

As a rule, the more active and more muscular an animal, the greater the demand for oxygen. Thus, warm-blooded animals live fast, and their rapidly decaying tissues call for rapid respiration; while in the cold-blooded creatures the waste is comparatively slow. Respiration is most active in birds, and least in water-breathing animals. The sluggish toad respires more slowly than the busy bee, the mollusk more slowly than the fish. But respirations, like beats of the heart, are fewer in large mammals than in small ones. An average man inhales about 300–400 cubic feet of air per day of rest, and much more when at work.

Another result of respiration, besides the purification of the blood, is the production of heat. The chemical combination of the oxygen in the air with the carbon in the tissues is a true combustion; and, therefore, the more active the animal and its breathing, the higher its temperature. Birds and mammals have a constant temperature, which is usually higher than that of the atmosphere (108° and 100° F. respectively). They are therefore

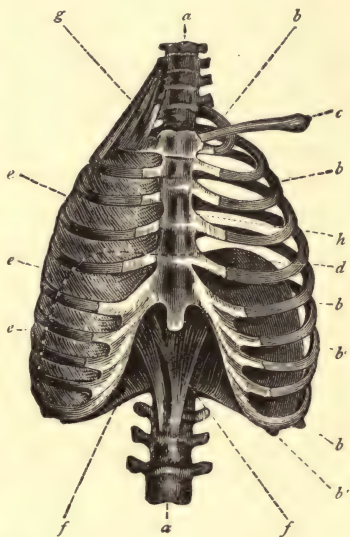


FIG. 285. — Human Thorax: *a*, vertebral column; *b*, *b'*, ribs, the lower ones false; *c*, clavicle; *e*, intercostal muscles, removed on the left side to show the diaphragm, *d*; *f*, pillars of the diaphragm attached to the lumbar vertebrae; *g*, muscles for elevating the ribs; *h*, sternum.

called *constant temperatured* or *warm blooded*. Other animals do not vary greatly in temperature from that of their surroundings, and are called *changeable temperatured* or *cold blooded*. Still, their temperature does not agree exactly with that of the air or water. The bee is from 3° to 10° , and the earthworm and snail from $1\frac{1}{2}^{\circ}$ to 2° , higher than the air. The mean temperature of the carp and toad is 51° ; of man, 98.5° ; dog, 99° ; cat, 101° ; squirrel, 105° ; swallow, 111° , all according to the Fahrenheit scale.

CHAPTER XVIII *

SECRETION AND EXCRETION

IN the circulation of the blood, not only are the nutrient materials taken around through the body to be used in the construction of various tissues, but certain special fluids are taken up and conveyed to the external or internal surfaces in the body, where, in glandular structures, further elaboration takes place. The resulting products are of two kinds: some, like saliva, gastric juice, bile, milk, etc., are for useful purposes; others, like sweat and urine, are expelled from the system as useless or injurious. The separation of the former is called *secretion*; the removal of the latter is *excretion*. Both processes are substantially alike.

In the lower forms, there are no special organs, but secretion and excretion take place from the general surface. The simplest form of a secreting organ closely resembles that of a respiratory organ, a thin membrane separating the blood from the cavity into which the secretion is to be poured. Usually, however, the cells of the membrane manufacture the secretion from materials furnished by the blood. Even in the higher animals, there are such secreting membranes. The membranes lining the nose and alimentary canal and inclosing the lungs, heart, and joints, secrete lubricating fluids.

The infolding of such a membrane into little sacs or short tubes (*follicles*), each having its own outlet, is the

* See Appendix.

type of all secreting and excreting organs. The lower animals have nothing more complex, and the apparatus for preparing the gastric fluid attains no further development even in man. When a cluster of these follicles, or sacs, discharge their contents by one common duct,

we have a *gland*. But whether membrane, follicle, or gland, the organ is covered with a network of blood vessels, and lined with epithelial cells, which are the real agents in the process.

The Chief Secreting Organs are the *salivary glands*, *gastric follicles*, *pancreas*, and *liver*, all situated along the digestive tract.

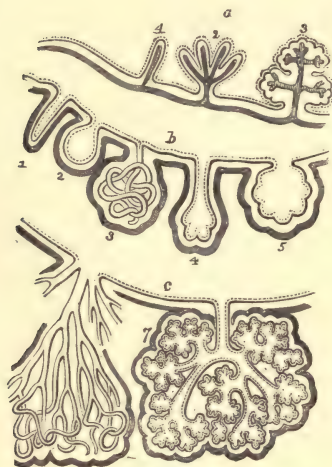


FIG. 286. — Three plans of secreting Membranes. The heavy line represents the areolar-vascular layer; the next line is the basement, or limiting membrane; and the dotted line the epithelial layer: *a*, shows increase of surface by simple plaited or fringed projections; *b*, five modes of increase by recesses, forming simple glands, or follicles; *c*, two forms of compound glands.

food. The saliva serves to lubricate or dissolve the food for swallowing, and, in some mammals, aids also in digestion of starch.¹²³

2. The gastric follicles are minute tubes in the walls of the stomach secreting gastric juice. They are found in all vertebrates, and in the higher mollusks and arthropods. In the lower forms, a simple membrane lined with cells serves the same purpose. Under the micro-

1. The salivary glands, which open into the mouth, secrete saliva. They exist in nearly all vertebrates, higher mollusks, and insects, and are most largely developed in such as live on vegetable

scope, the soft mucous membrane of the human stomach presents a honeycomb appearance, caused by numerous depressions or cells. At the bottom of these depressions are clusters of spots, which are the orifices of the tubular follicles. The follicles are about $\frac{1}{250}$ of an inch in diameter, and number millions.

3. The pancreas, or "sweetbread," so important in the process of digestion, exists in all but the lowest animals. In its structure it closely resembles the salivary glands. In the cuttlefish, it is represented by a sac; in fishes, by a group of follicles. It is proportionally largest in birds whose salivary glands are deficient. The pancreatic juice enters the duodenum.

4. A so-called "liver" is found in all animals having a distinct digestive cavity. In the lower animals its function has been shown to be that of a pancreas. Thus, in polyps it is represented by yellowish cells lining the stomach; in insects, by cells in the wall of the stomach; in mollusks, by a cluster of sacs, or follicles, forming a loose compound gland.

In vertebrates, a true liver, the largest gland in the body, is well defined, and composed of a multitude of lobules (which give it a granular appearance) arranged on the capillary veins, like grapes on a stem, and containing nucleated

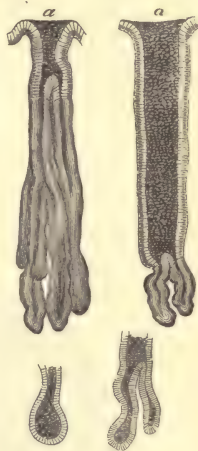


FIG. 287. — Follicles from the Stomach of a Dog, $\times 150$; near the mouth, *a*, there is a lining of columnar epithelium.



FIG. 288. — Pancreas of Man; *o*, pancreas; *g*, gall bladder; *s*, cystic duct; *c*, duct from the liver; *p*, pyloric valve; *e, i*, duodenum.

secreting cells. It is of variable shape, but usually two, three, or five lobed, and is centrally situated — in mammals, just below the diaphragm. In most vertebrates, there is an appendage to the liver called the *gall bladder*, which is simply a reservoir for the bile.

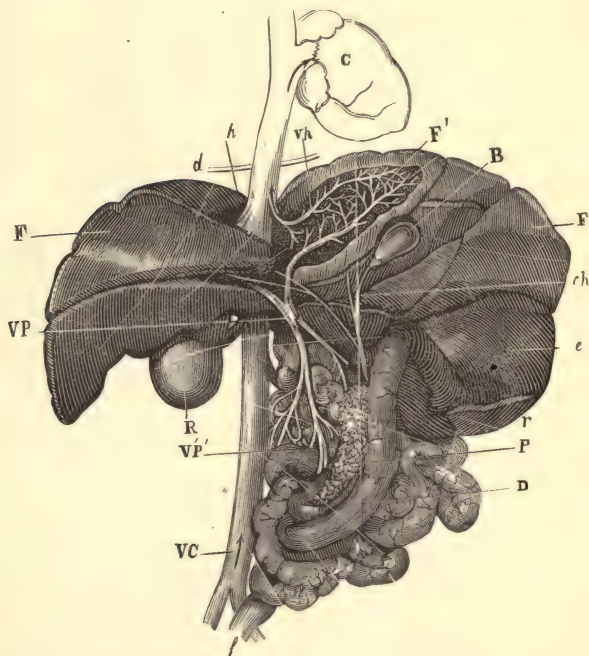


FIG. 289. — Liver of the Dog: F, F, liver; D, duodenum and intestines; P, pancreas; *r*, spleen; *e*, stomach, *f*, rectum; R, right kidney; B, gall bladder; *ch*, cystic duct; F', lobe of liver dissected to show distribution of portal vein, VP, and hepatic vein, *vh*; *d*, diaphragm; VC, vena cava; C, heart.

The so-called liver of invertebrates is more like the pancreas of vertebrates in function, as its secretion digests starches and albuminoids. The liver of vertebrates is both a secretory and an excretory organ. The bile performs an important, although ill-understood, function in digestion, and also contains some waste products.

The gland also serves to form sugar (glycogen) from part of the digested food, and may well be called a chemical workshop for the body. In animals of slow respiration, as crustaceans, mollusks, fishes, and reptiles, fat accumulates in the liver. "Cod-liver oil" is an example.

The Great Excreting Organs are the *lungs*, the *kidneys*, and the *skin*; and the substances which they remove from the system — carbonic acid, water, and urea — are the products of decomposition, or organic matter on its way back to the mineral kingdom.¹²⁴ Different as these organs appear, they are constructed upon the same principle: each consisting of a very thin sheet of tissue separating the blood to be purified from the atmosphere, and straining out, as it were, the noxious matters. All, moreover, excrete the same substances, but in very different proportions: the lungs exhale carbon dioxide and water, with a trace of urea; the kidneys expel water, urea, and a little carbon dioxide; while the skin partakes of the nature of both, for it is not only respiratory, especially among the lower animals, but it performs part of the work of the kidneys in case they are diseased.

1. The lungs (and likewise gills) are mainly excretory organs. The oxygen they impart sweeps with the blood through every part of the body, and unites with the tissues and with some elements of the blood. Thus are produced heat and work, whether muscular, nervous, secretory, etc. As a result of this oxidation, carbon dioxide, water, and urea, or a similar substance, are poured into the blood. The carbon dioxide and part of the water are passed off from the respiratory organs. This process is more immediately necessary to life than any other; the arrest of respiration is fatal.

2. While the lungs (and skin also, to a slight degree) are sources of gain as well as loss to the blood, the kid-

neys are purely excretory organs. Their main function is to eliminate the solid products of decay which can not



FIG. 290. — Section of Human Kidney, showing the tubular portion, 3, grouped into cones; 7, the ureter, or outlet for the secretion.

pass out by the lungs. In mammals, they are discharged in solution; but from other animals which drink little the excretion is more or less solid. In insects, the kidneys are groups of tubes (Figs. 239, 240); in the higher mollusks, they are represented by spongy masses of follicles (Fig. 244); in vertebrates, they are well-developed glands, two in number, and consist of closely packed tubes.

3. The skin of the soft-skinned animals, particularly of amphibians and mammals, is covered with

minute pores, which are the ends of as many delicate tubes that lie coiled up into a knot within the true skin. These are the sweat glands, which excrete water, and with it certain salts and gases.

Besides these secretions and excretions, there are others, confined to particular animals, and designed for special purposes: such are the oily matters secreted from the skin of quadrupeds for lubricating the hair and keeping the skin flexible; the tears of reptiles, birds, and mammals; the milk of mammals; the ink of the cuttlefish; the poison of jellyfishes, insects, and snakes; and the silk of spiders and caterpillars.

CHAPTER XIX *

THE SKIN AND SKELETON

The Skin, or Integument, is that layer of tissue which covers the outer surface of the body. The term **Skeleton** is applied to the hard parts of the body, whether external or internal, which serve as a framework or protection to the softer organs, and afford points of attachment to muscles. If external, as the crust of the lobster, it is called *exoskeleton*; if internal, as the bones of man, it is called *endoskeleton*. The former is a modification of the skin; the latter, a hardening of the deeper tissues.

1. The Skin. — In the lowest forms of life, as amœba, there is no skin. The protoplasm of which they are composed is firmer outside than inside, but no membrane is present. In Infusoria, there is a very thin “cuticle” covering the animal (Fig. 9). They have thus a definite form, while the amœbas continually change. Sponges and hydras also have no true skin. But in polyps, the outside layer of the animal is separated into two portions — ectoderm and endoderm¹²⁵ — which may be regarded as partly equivalent to epidermis and dermis in the higher animals. These two layers are, then, generally present. The outer is cellular, the latter fibrous, and may contain muscular fibers, blood vessels, nerves, touch organs, and glands. It thus becomes very complicated in some animals.

* See Appendix.

In worms and arthropods, the cellular layer, here called hypodermis, excretes a structureless cuticle, which may become very thick, as in the tail of the horseshoe crab, or may be hardened by deposition of lime salts, as in many Crustacea. The loose skin, called the *mantle*, which envelops the body of the mollusk, corresponds to the true skin of higher animals. The border of the mantle is surrounded with a delicate fringe, and, moreover, contains minute glands, which secrete the shell and the coloring matter by which it is adorned. The tunicates have a leathery epidermis, remarkable for containing vegetable cellulose instead of lime.

In mammals, whose skin is most fully developed, the dermis is a sheet of tough elastic tissue, consisting of interlacing fibers, and containing blood vessels, lymphatics, sweat glands, and nerves. It is the part converted into leather when hides are tanned, and attains the extreme thickness of three inches in the rhinoceros. The upper surface in parts of the body is covered with a vast number of minute projections, called *papillæ*, each containing the termination of a nerve; these are the essential agents in the sense of touch¹²⁶ (Fig. 345). They are best seen on the tongue of an ox or cat, and on the human fingers, where they are arranged in rows.

Covering this sensitive layer, and accurately molded to all its furrows and ridges, lies the bloodless and nerveless epidermis. It is that part of the skin which is raised in a blister. It is thickest where there is most pressure or hard usage; on the back of the camel it attains unusual thickness. The lower portion of the epidermis (called *rete mucosum*) is comparatively soft, and consists of nucleated cells containing pigment granules, on which the color of the animal depends. Toward the surface the cells become flattened, and finally, on the outside, are changed to horny scales (Fig. 199, c).

These scales in the higher animals are constantly wearing off in the form of scurf, and as constantly being renewed from below. In lizards and serpents, the old epidermis is cast entire, being stripped off from the head to the tail; in the toad it comes off in two pieces; in the frog, in shreds; in fishes and some mollusks, in the form of slime. However modified the epidermis, or whatever its appendages, the like process of removal

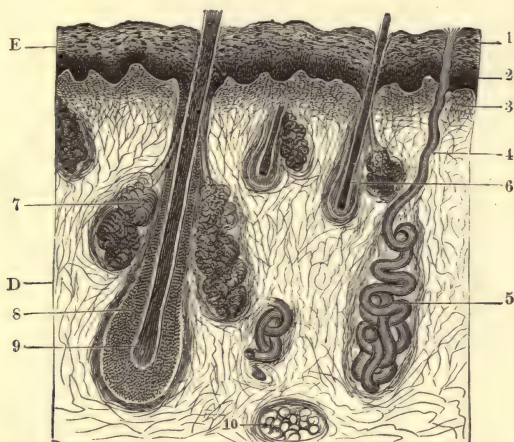


FIG. 291. — Section of Skin from Horse's Nostril (magnified): E, epidermis; D, dermis; 1, horny layer of epidermis; 2, rete mucosum; 3, papillary layer of dermis; 4, excretory duct of a sudoriparous, or sweat, gland; 5, glomerule, or convoluted tube of the same; 6, hair follicle; 7, sebaceous gland; 8, internal sheath of the hair follicle; 9, bulb of the hair; 10, mass of adipose tissue.

goes on. Mammals shed their hair; birds, their feathers; and crabs, their shells. When the loss is periodical, it is termed molting.

2. The Skeletons. — (1) **The Exoskeleton** is developed by the hardening of the skin, and, with very few exceptions, is the only kind of skeleton possessed by invertebrate animals. The usual forms are coral, shells, crusts, scales, plates, hairs, and feathers. It is horny or calcareous; while the *endoskeleton* is generally a deposit

of earthy material within the body, and is nearly confined to the vertebrates. The exoskeleton may be of two kinds — dermal and epidermal.

Some of the Protozoa, as *Radiolaria* and *Foraminifera*, possess siliceous and calcareous shells of the most beautiful patterns (Fig. 2). The toilet sponge has a skeleton of horny fibers, which is the sponge of commerce. Coral is the solid framework of certain polyps. There are two kinds: one represented by the common

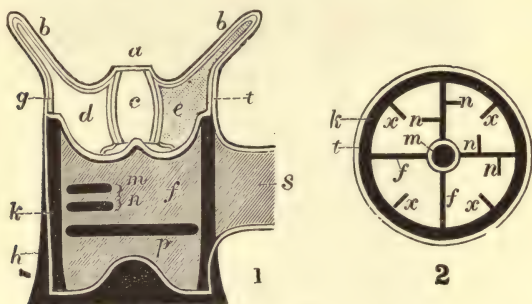


FIG. 292. — 1, Vertical Section, and, 2, Transverse Section, of a sclerodermic Corallite: *a*, mouth; *b*, tentacles; *c*, stomach; *d*, intermesenteric chamber; *e*, mesentery; *f*, septum; *g*, endoderm; *h*, epitheca; *k*, theca, or outer wall; *m*, columella; *n*, short partitions; *p*, tabula, or transverse partition; *r*, sclerobase; *s*, coenenchyma, or common substance connecting neighboring corallites; *t*, ectoderm; *x*, pali, or imperfect partitions.

white coral, which is a calcareous secretion within the body of the polyp, in the form of a cylinder, with partitions radiating toward a center (*scleroderm*); the other, represented by the solid red coral of jewelry, is a central axis deposited by a group of polyps on the outside (*sclerobase*).

The skeleton of the starfish is a leathery skin in which are embedded calcareous particles and plates. The sea urchin is covered with an inflexible shell of elaborate and beautiful construction. The shell is really a calcified skin, being a network of fibrous tissue and

earthy plates. It varies in shape from a sphere to a disk, and consists of hundreds of angular pieces accurately fitted together, like mosaic work. These form ten zones, like the ribs of a melon, five broad ones alternating with five narrower ones. The former (called *inter-ambulacra*) are covered with

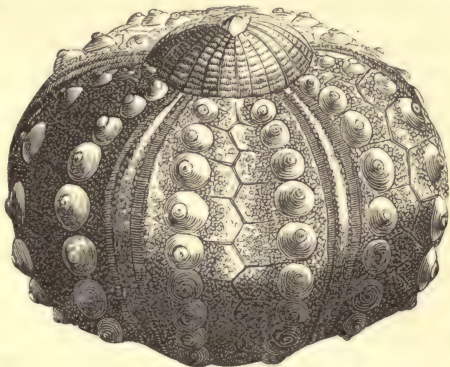


FIG. 293. — Shell of Sea Urchin (*Cidarid*) without its spines.

tubercles bearing movable spines. The narrow zones (called *ambulacra*, as they are likened to walks through a forest) are pierced with small holes, through which project fleshy sucker feet.

The skin of the lobster is hardened by calcareous deposit into a "crust," or shell;¹²⁷ but, instead of

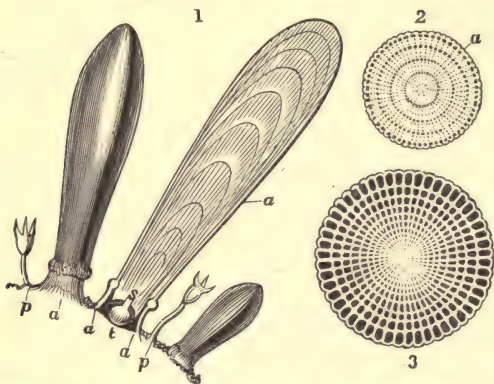


FIG. 294. — Structure of Sea Urchins' Spines (magnified): 1, *a*, spine of *Cidarid* cut longitudinally; *t*, *s*, ball-and-socket joint; *p*, pedicellariæ; 2, 3, transverse sections of spines of *Cidarid* and *Echinus*.

forming one piece, it is divided into a series of segments, which move on each other. The number of these segments, or rings, is usually twenty — five in the head,

eight in the thorax, and seven in the abdomen. In the adult, however, the rings of the head and thorax are often soldered together into one shield, called *cephalothorax*; and in the horseshoe crab the abdominal rings are also united. The shell of crustaceans is periodically

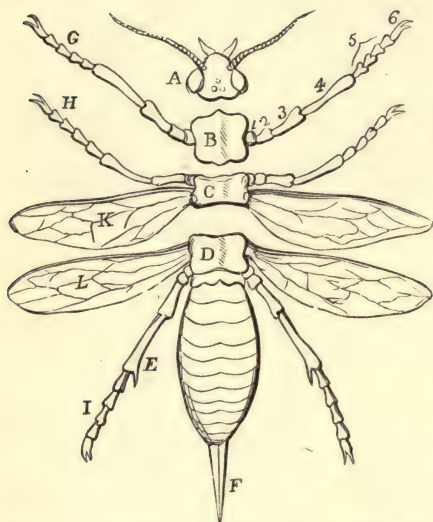


FIG. 295. — Diagram of an Insect: A, head bearing the eyes and antennæ; B, prothorax, carrying the first pair of legs, G; C, mesothorax, carrying the second pair of legs, H, and first pair of wings, K; D, metathorax, carrying the third pair of legs, I, and second pair of wings, L; E, abdomen, with ovipositor, F; 1, coxa, or hip; 2, trochanter; 3, femur, or thigh; 4, tibia, or shank; 5, tarsus, or foot; 6, claw.

cast off, for the animals continue to grow even after they have reached their mature form. This molting is a very remarkable operation. How the lobster can draw its legs from their cases without unjointing or splitting them was long a puzzle. The flesh becomes soft, and is drawn through the joints, the wounds thus caused quickly healing. The cast-off skeleton

is a perfect copy of the animal, retaining in their places the delicate coverings of the eyes and antennæ, and even the lining membrane of the stomach with its teeth.

The horny crust of insects differs from that of crustaceans in consisting mainly of a horny substance called chitin and in containing no lime. The head, thorax, and abdomen are distinct, and usually consist of fourteen visible segments — one for the head, three for the

thorax (called *prothorax*, *mesothorax*, *metathorax*), and ten for the abdomen. The antennæ, or feelers, legs, and wings, as well as hairs, spines, and scales, are appendages of the skeleton. As insects grow only during the larval, or caterpillar, state, molting is confined to that period. These skeletons are epidermal, deposited in successive layers, from the inside, and are, therefore, capable of but slight enlargement when once formed.

The shells of mollusks are well-known examples of exoskeletons. The mantle, or loose skin, of these animals secretes calcareous earth in successive layers, converting the epidermis into a "shell."¹²⁸ So various and characteristic is the microscopic character of shells, that a fragment is sometimes sufficient to determine the group to which it belongs. Many shells resemble that of the fresh-water mussel (*Unio*), which is composed of three parts: the external brown epidermis, of horny texture; then the prismatic portion, consisting of minute columns set perpendicularly to the surface; and the internal nacreous layer, or "mother-of-pearl," made up of exceedingly thin plates. The pearly luster of the last is due to light falling upon the outcropping edges of wavy laminæ.¹²⁹ In many cases, the prismatic and nacreous layers are traversed by minute tubes. Another typical shell structure is seen in the common cone, a section of which shows three layers, besides the epidermis, consisting of minute plates set at different angles. The nautilus shell is composed of two distinct layers: the outer one having the fracture of broken china; the inner one, nacreous.

Most living shells are made of one piece, as the snail; these are called "univalves." Others, as the clam, consist of two parts, and are called "bivalves." In either case, a valve may be regarded as a hollow cone, grow-

ing in a spiral form. The ribs, ridges, or spines on the outside of a shell mark the successive periods of growth, and, therefore, correspond to the age of the animal. Figures 296 and 297 show the principal parts of the ordinary bivalves and univalves.

The valves of a bivalve are generally equal, and the umbones, or beaks, a little in front of the center. The valves are bound to-

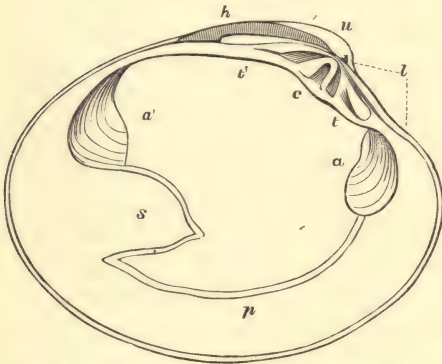


FIG. 296. — Left Valve of a Bivalve Mollusk (*Cytherea chione*): *h*, hinge ligament; *u*, umbo; *l*, lunule; *c*, cardinal, and *t*, *t'*, lateral teeth; *a*, *a'*, impressions of the anterior and posterior adductor muscles; *p*, pallial impression; *s*, sinus, occupied by the retractor of the siphons.

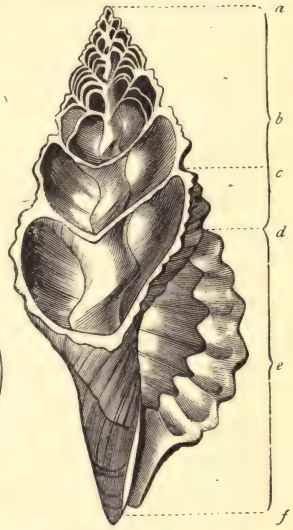


FIG. 297. — Section of a Spiral Univalve (*Triton corrugatus*): *a*, apex; *b*, spire; *c*, suture; *d*, posterior canal; *e*, outer lip of the aperture; *f*, anterior canal.

gether by a ligature near the umbones, and often, also, by means of a "hinge" formed by the "teeth" of one valve interlocking into cavities in the other. The aperture of a univalve is frequently closed by a horny or calcareous plate, called "operculum," which the animal carries on the back of the hinder portion of its foot, and which is a part of the exoskeleton. The shells of mollusks are epidermal, and are, therefore, dead and incapable of true repair. When broken, they can be mended only by the animal pouring out lime to cement

the parts together. They can not grow together, like a broken bone.

Embedded in the back of the cuttlefish is a very light spongy "bone," which, as already observed, is a secretion from the skin, and therefore belongs to the exoskeleton. It has no resemblance to true bone, but is formed, like shells, of a number of calcareous plates. Nevertheless, the cuttlefish does exhibit traces of an endoskeleton: these are plates of cartilage, one of which surrounds the brain, and hence may be called a skull. To this cartilage, not to the "cuttlebone," the muscles are attached.

In vertebrates, the exoskeleton is subordinate to the endoskeleton, and is feebly developed in comparison.

It is represented by a great variety of appendages to the skin, which are mainly organs for protection, not for support.

Some are horny outgrowths of the epidermis, such as hairs, feathers, nails, claws, hoofs, horns, and the scales of reptiles;

others arise from the hardening of the dermis by calcareous matter, as the scales of fishes, the bony plates of crocodiles and turtles, and the shield of the armadillo.

The scales of fishes (and likewise the spines of their vertical fins) lie embedded in the overlapping folds of the skin, and are covered with a thin, slimy epidermis. The scales of the bony fishes (perch, salmon, etc.) consist of two layers, slightly calcareous, and marked by concentric and radiating lines. Those of the shark

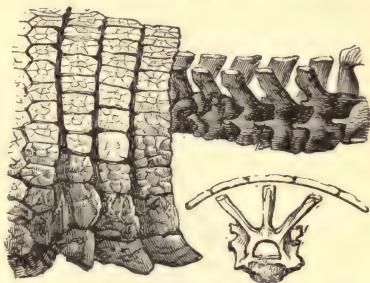


FIG. 298. — Skeletal Architecture in the Armadillo, showing the relation of the carapax to the vertebral column.

have the structure of teeth, while the scutes, or plates, of the crocodiles, turtles, and armadillos are of true bone.

The scales of snakes and lizards are horny epidermal plates covering the overlapping folds of the true skin.

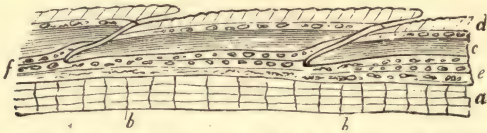


FIG. 299. — Diagrammatic Section of the Skin of a Fish (*Carp*): *a*, derm, showing laminated structure with vertical fibers, *b*; *c*, gristly layer; *e*, laminated layer, with calcareous granules; *d*, superficial portion developing into scales; *f*, scale pit.

In some turtles these plates are of great size, and are called “tortoise shell”; they cover the scutes. The scales on the legs of birds, and on the tail of the beaver and rat, have the same structure. Nails are flattened

horny plates developed from the upper surface of the fingers and toes. Claws are sharp conical nails, being developed from the sides as well as upper surface; and hoofs are blunt cylindrical claws. Hollow horns, as of the ox, may be likened to claws sheathing a bony core. The

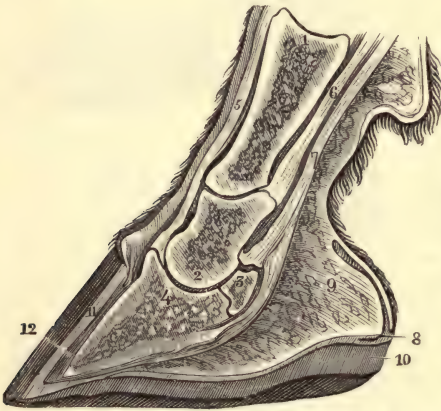


FIG. 300. — Vertical Section of the Forefoot of the Horse (middle digit): 1, 2, 4, proximal, middle, and distal, or ungual, phalanges; 3, sesamoid, or nut bone; 5, 6, 7, tendons; 9, elastic tissue; 8, 10, internal and external floor of the hoof; 11, 12, internal and external walls.

horn of the rhinoceros is a solid mass of epidermal fibers. “Whalebone,” the rattle of the rattlesnake, and the beaks of turtles and birds, are likewise epidermal.

Hairs, the characteristic clothing of mammals, are elongated horny cones, composed of "pith" and "crust." The latter is an outer layer of minute overlapping scales, which are directed toward the point, so that rubbing a human hair or fiber of wool between the thumb and finger pushes the root end away. The root is bulbous, and is contained in a minute depression, or sac, formed by an infolding of the



FIG. 301.—Section of the Root and part of the Shaft of a Human Hair, highly magnified: it is covered with epidermic scales, *b*, the inner layer, *c*, forming the outer covering of the shaft, *e*, being imbricated; the root consists of angular cells loaded with pigment; *d*, bulb.



FIG. 302.—Parts of a Feather: *a*, quill, or barrel; *b*, shaft; *c*, vane, or beard; *d*, accessory plume, or down; *e*, *f*, lower and upper umbilicus, or orifice, leading to the interior of the quill.

skin. Hairs are usually set obliquely into the skin. Porcupine's quills and hedgehog's spines make an easy transition to feathers, which differ from hairs only in splitting up into numerous laminae. They are the most

complicated of all the modifications of the epidermis. They consist of a "quill" (answering to the bulb of a hair), and a "shaft," supporting the "vane," which is made up of "barbs," "barbules," and interlocking "processes." The quill alone is hollow, and has an orifice at each end. The feather is molded on a papilla, the shaft lying in a groove on one side of it, and the vane wrapped around it. When the feather emerges from the skin, it unfolds itself. Thus shaft and vanes together resemble the quill split down one side and spread out.

The teeth of mollusks, worms, and arthropods are also epidermal structures. Those of vertebrates are mixed in their origin, the dentine being derived from the dermis and the enamel from the epidermis. In all cases teeth belong to the exoskeleton.

(2) **The Endoskeleton**, as we have seen, is represented in the cuttlefish. With this and some other exceptions, it is peculiar to vertebrates. In the cuttlefish, and some fishes, as the sturgeon and shark, it consists of cartilage; but in all others (when adult) it is bone or osseous tissue. Yet there is a diversity in the composition of bony skeletons; that of fresh-water fishes contains the least earthy matter, and that of birds the most. Hence the density and ivory-whiteness of the bones of the latter. Unlike the shells of mollusks and the crust of the lobster, which grow by the addition of layers to their borders, bones are moist, living parts, penetrated by blood vessels and nerves, and covered with a tough membrane, called *periosteum*, for the attachment of muscles.

The surface of bones is compact; but the interior may be solid or spongy (as the bones of fishes, turtles, sloths, and whales), or hollow (as the long bones of birds and the active quadrupeds). There are also cavi-

ties (called *sinuses*) between the inner and outer walls of the skull, as is remarkably shown by the elephant. The cavities in the long bones of quadrupeds are filled with marrow; those in the long bones of most birds and in skulls contain air.

The number of bones not only differs in different animals, but varies with the age of an individual. In very early life there are no bones at all; and ossification, or the conversion of cartilage into bone, is not completed until maturity. This process begins at a multitude of points, and theoretically there are as many bones in a skeleton as centers of ossification. But the actual number is usually much less—a result of the tendency of these centers to coalesce. Thus, the thigh bone in youth is composed of five distinct portions, which gradually unite. So in the lower vertebrates many parts remain distinct which in the higher are joined into one. The occiput or bone at the base of man's skull is the union of four bones, which are seen separate in the skull of the fish, or of a baby.

A complete skeleton, made up of all the pieces which might enter into its composition, does not exist. Every vertebrate has some deficiency. All, except amphioxus, have a skull and backbone; but in the development of the various parts, and especially of the appendages, there is endless variety. Fishes possess a great number of skull bones, but have no fingers and toes. The snake has plenty of ribs and tail, but no breastbone; the frog has a breastbone, but neither tail nor ribs. As the skeleton of a fish is too complicated for the primary student, we will select for illustration the skeleton of a lion—the type of quadrupeds. It should be remembered, however, that all vertebrates are formed on one plan.

In the lowest vertebrate, amphioxus, the only skeleton is a cartilaginous rod running from head to tail.

There is no skull, nor ribs, nor limbs. In the cartilaginous fishes, the backbone is only partially ossified. But usually it consists of a number of separate bones,

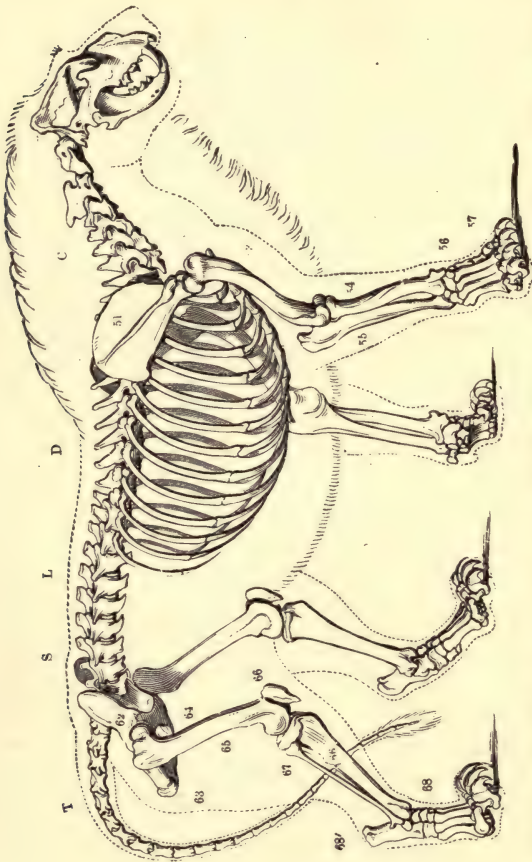


FIG. 303. — Skeleton of the Lion (*Felis leo*): C, cervical vertebrae; D, dorsal; L, lumbar; S, sacral; T, caudal (the vertebral column of the Lion differs from that of the Dog only in having from 8 to 10 more caudals); 51, scapula; 53, humerus; 54, radius; 55, ulna; 56, carpus; 57, metacarpus; 62, ilium; 63, ischium; 64, pubic arch; 65, femur; 66, patella; 66', tibia; 67, fibula; 68, heel, or calcaneum; 68', tarsus.

called *vertebrae*, arranged along the axis of the body. They range in number from 10 in the frog to 305 in the boa constrictor. The skull, with its appendages, and the *vertebrae*, with the ribs and sternum, make

up the *axial skeleton*. The shoulder and pelvic girdles and the skeleton of the limbs constitute the *appendicular skeleton*.

A typical vertebra consists of a number of bony pieces so arranged as to form two arches, or hoops, connected by a central bone, or *centrum*.¹³⁰ The upper hoop is called the *neural arch*, because it encircles the spinal cord; the lower hoop is called the *hemal arch*, because it incloses the heart and the great central blood vessels. An actual vertebra, however, is subject to so

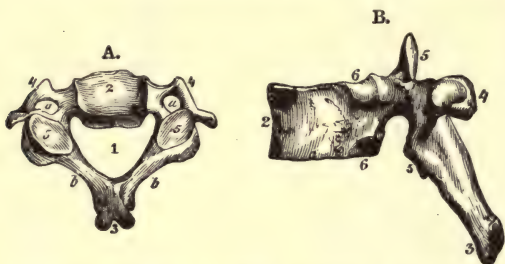


FIG. 304. — Vertebrae — A, cervical; B, dorsal; 2, centrum; 4, transverse process, containing foramen, *a*, for artery; 5, articular process; 3, spinous process, or neural spine; 1, neural canal; 6, facets for head of rib, the tubercle of the rib fitting in a facet on the process, 4; *b*, laminae, or neurapophyses.

many modifications, that it deviates more or less from this ideal type. Selecting one from the middle of the back for an example, we see that the centrum sends off from its dorsal side two branches, or processes, called *neurapophyses*. These meet to form the neural arch, under which is the *neural canal*, and above which is a process called the *neural spine*. On the anterior and posterior edges of the arch are smooth surfaces, or *zygapophyses*, which in the natural state are covered with cartilage, and come in contact with the corresponding surfaces of the preceding and succeeding vertebrae. The bases of the arch are notched in front and behind, so that when two vertebrae are put together a round

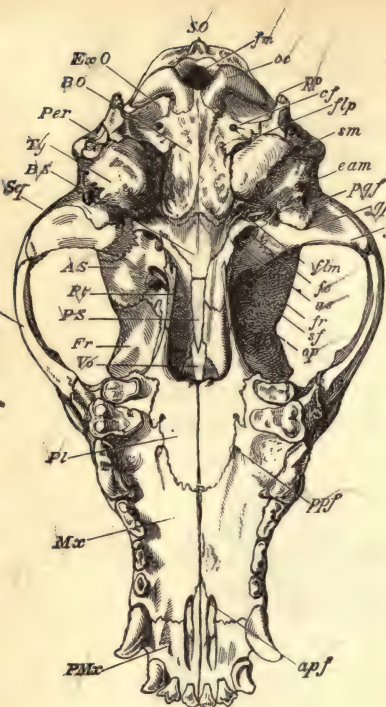


FIG. 305.

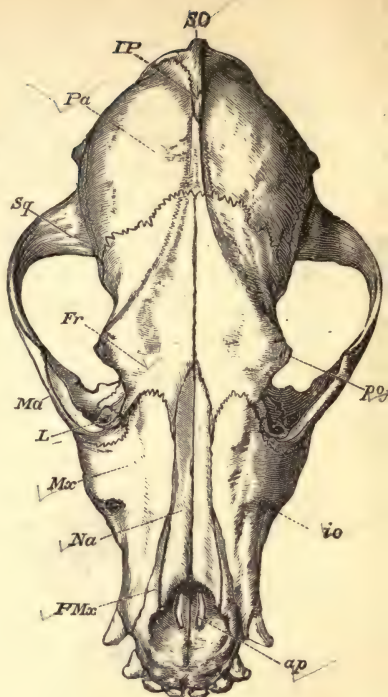


FIG. 306.

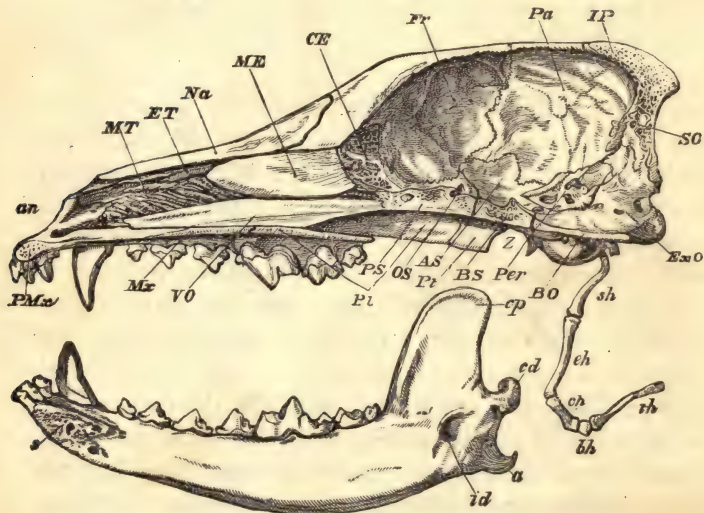


FIG. 307.

opening (*intervertebral foramen*) appears between the pair, giving passage to the nerves issuing from the spinal cord. From the sides of the arch, blunt transverse processes project outward and backward, called *diapophyses*. Such are the main elements in a representative vertebra. The hemal arch is not formed by any part of the vertebra, but by the ribs and breastbone. Theoretically, however, the ribs are considered as elongated processes from the centrum (*pleurapophyses*), and in a few cases a *hemal spine* is developed corresponding to the neural spine.

The vertebræ are united together by ligaments, but chiefly by a very tough, dense, and elastic substance between the centra. The neural arches form a continuous canal which contains and protects the spinal cord; hence the vertebral column is called the *neuroskeleton*. The column is always more or less curved; but the beautiful sigmoid curvature is peculiar to man. The vertebræ gradually increase in size from the head toward the end of the trunk, and then diminish to the end of the tail. The neural arch and centrum are seldom wanting; the first vertebra in the neck has no centrum, and the last in the tail is all centrum. The vertebræ of the extremities (head and tail) depart most widely from the typical form.

The vertebral column in fishes and snakes is divisible into three regions — head, trunk, and tail. In the higher animals there are six divisions of the vertebral column, the *skull*, and *cervical*, *dorsal*, *lumbar*, *sacral*, and *caudal vertebræ*.

The *skull*¹³¹ is formed of bones whose shape varies greatly from that of typical vertebræ. The number of distinct bones composing the skull is greatest in fishes, and least in birds; this arises partly from the fact that the bones remain separate in the former case, while

those of the chick become united together (*anchylosed*) in the full-grown bird; but many bones are present in the fish which have no representatives in the bird. The skull consists of the brain case and the face. The principal parts of the skull, as shown in the dog's, are:

1. The *occipital* bone behind, inclosing a large hole, or *foramen magnum*, on each side of which are rounded prominences, called *condyles*, by which the skull articu-

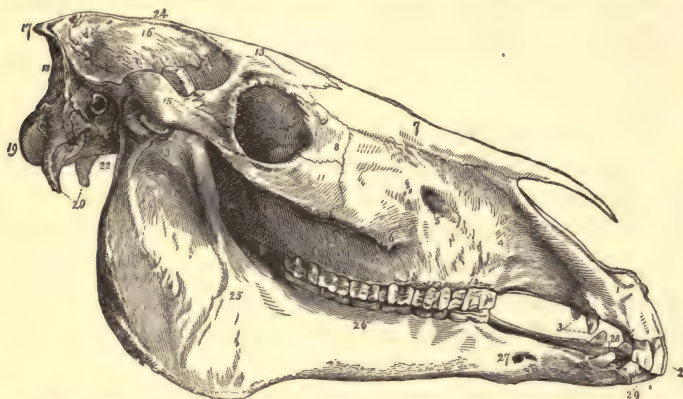


FIG. 308. — Skull of the Horse: 1, premaxillary bone; 2, upper incisors; 3, upper canines; 4, superior maxillary; 5, infraorbital foramen; 6, superior maxillary spine; 7, nasal bones; 8, lachrymal; 9, orbital cavity; 10, lachrymal fossa; 11, malar; 12, upper molars; 13, frontal; 15, zygomatic arch; 16, parietal; 17, occipital protuberance; 18, occipital crest; 19, occipital condyles; 20, styloid processes; 21, petrous bone; 22, basilar process; 23, condyle of inferior maxillary; 24, parietal crest; 25, inferior maxillary; 26, lower molars; 27, anterior maxillary foramen; 28, lower canines; 29, lower incisors.

lates with the first cervical vertebra. 2. The two *parietal* bones. 3. The two *frontal* bones. These five form the main walls of the skull. 4. The *sphenoid*, on the floor of the skull in front of the occipital, and consisting of six pieces. 5. The two *temporal* bones, in which are situated the ears. In man each temporal is a single bone; but in most animals there are three or more — the *periotic*, *tympanic*, and *squamosal*. 6. The *malars*, or “cheek bones,” each of which sends back a

process to meet one from the squamosal, forming the *zygomatic arch*. 7. The two *nasals*, forming the roof of the nose. 8. The two *maxillæ*, that part of the upper jaw in which the canines, premolars, and molars are lodged. 9. The two *premaxillæ*, in which the upper incisors are situated. 10. The two *palatines*, which, with the maxillary bones, form the roof of the mouth. There are two appendages to the skull: the *mandible*, or lower jaw, whose condyles, or rounded extremities, fit into a cavity (the *glenoid*) in the temporal bone; and the *hyoid* bone, situated at the root of the tongue.

The simplest form of the skull is a cartilaginous box, as in sharks, inclosing the brain and supporting the cartilaginous jaws and gill arches. In higher fishes this box is overlaid with bony plates and partly ossified. In frogs the skull is mainly bony, although a good deal of the cartilage remains inside the bones. In higher vertebrates the cartilage never makes an entire box, and early disappears.

The *cervical vertebræ*, or bones of the neck, are peculiar in having an orifice on each side of the centrum for the passage of an artery. The first, called *atlas*, because it supports the head, has no centrum, and turns on the second, called *axis*, around a blunt peglike projection, called the *odontoid process*. The centra are usually wider than deep, and the neural spines very short, except on the last one. The number of cervical vertebræ ranges from 1 in the frog to 25 in the swan.

The *dorsal vertebræ* are such as bear ribs, which, uniting with the breastbone, or *sternum*, form a bony arch over the heart and lungs, called the *thorax*. The sternum may be wanting, as in fishes and snakes, or greatly developed, as in birds. When present, the first vertebra whose ribs are connected with it is the first dorsal.

The neural spines of the dorsal series are generally long, pointing backward.

The *lumbar vertebræ* are the massive vertebræ lying in the loins between the dorsals and the hip bones.

The *sacral vertebræ* lie between the hip bones, and are generally consolidated into one complex bone, called *sacrum*.

The *caudal vertebræ* are placed behind the sacrum, and form the tail. They diminish in size, losing processes and neural arch, till finally nothing is left but the centrum. They number from 3 or 4 in man to 270 in the shark.

Besides the lower jaw, hyoid, and ribs, vertebrates have other appendages to the spinal column — two pairs of *limbs*.¹³² The fore limb is divided into the *pectoral arch* (or *shoulder girdle*), the *arm*, and the *hand*. The arch is fastened to the ribs and vertebræ by powerful muscles, and consists of three bones, the *scapula*, or shoulder blade, the *coracoid*, and the *clavicle*, or collar bone. The scapula and coracoid are generally united in mammals, the latter being a process of the former; and the clavicles are frequently wanting, as in the hoofed animals. The *humerus*, *radius*, and *ulna* are the bones of the arm, the first articulating by ball and socket joint with the scapula, and by a hinge joint with the radius and ulna. The humerus and radius are always present, but the ulna may be absent. The bones of the hand are divided into those of the *carpus*, or wrist; the *metacarpus*, or palm; and the *phalanges*, or fingers. The fingers, or "digits," range in number from 1 to 5.

The hind limb is composed of the *pelvic arch* (or hip bones), the *leg*, and the *foot*. These parts correspond closely with the skeleton of the fore limb. Like the shoulder, the pelvic arch, or *os innominatum*, consists of three bones — *ilium*, *ischium*, and *pubis*. The three are

distinct in amphibians, reptiles, and in the young of higher animals; but in adult birds and mammals they become united together, and are also (except in whales) solidly attached to the sacrum. The two pelvic arches and the sacrum thus soldered into one make the *pelvis*. The leg bones consists of the *femur*, or thigh; the *tibia*, or shin bone; and the *fibula* or splint bone. The rounded head of the femur fits into a cavity (*acetabulum*) in the pelvic arch, while the lower end articulates with the tibia, and sometimes (as in birds) with the fibula also. An extra bone, the *patella*, or kneepan, is hung in a tendon in front of the joint between the femur and tibia of the higher animals. The foot is made up of the *tarsus*, or ankle; the *metatarsus*, or lower instep; and the *phalanges*, or toes. The toes number from 1 in the horse to 5 in man.

Certain parts of the skeleton, as of the skull, are firmly joined together by zigzag edges or by overlapping; in either case the joint is called a *suture*. But the great majority of the bones are intended to move one upon another. The vertebræ are locked together by their processes, and also by a tough fibrous substance between the centra, so that a slight motion only is allowed. The limbs furnish the best examples of movable articulations, as the ball and socket joint at the shoulder, and the hinge joint at the elbow. The bones are held together by ligaments, and to prevent friction, the extremities are covered with cartilage, which is constantly lubricated with an unctuous fluid called *synovia*.

A chemical analysis of bone shows it to consist mainly of phosphate and carbonate of lime and phosphate of magnesia mingled with gluten, chondrin, and oil, the amount of each varying in different animals.

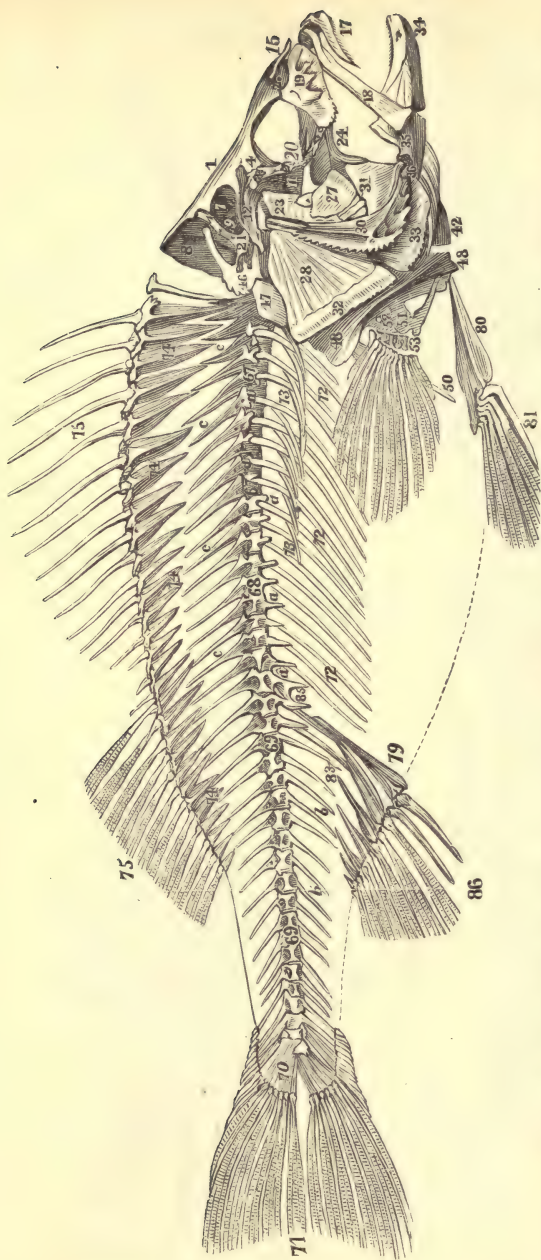


FIG. 309. — Skeleton of the Perch (*Perca fluviatilis*): 1, frontal; 4, postfrontal; 7, parietal; 8, supraoccipital; 9, exoccipital; 11, proötic; 12, pterotic; 15, nasal; 17, premaxillary; 18, maxillary; 19, prenasal; 20, suborbital plates; 21, supratergital plates (peculiar to fishes); 23, mastotemporal; 24, ectopterygoid; 27, metapterygoid; 28, operculum, or flap, closing the gill openings; 30, preoperculum; 31, quadrate; 32, suboperculum; 33, interoperculum; 34, dentary — that part of the lower jaw containing the teeth; 35, articular; 36, angular; 42, urohyal, lying between the branches of the os hyoides; 46, post temporal; 47, supracleivle; 48, clavicle; 50, digital rays of pectoral fin; 51, coracoid; 52, scapula; 53, basal cartilages; 67, 68, abdominal vertebrae; 69, caudal; 70, attachment of the caudal fin; 71; 72, ribs; 73, styliform processes; 74, 79, interspinous bones; 75, dorsal fins; 80, pelvic fins; 81, ventral fin; 83, δ , haemal spines; 85, α , parapophyses; 86, anal fin.

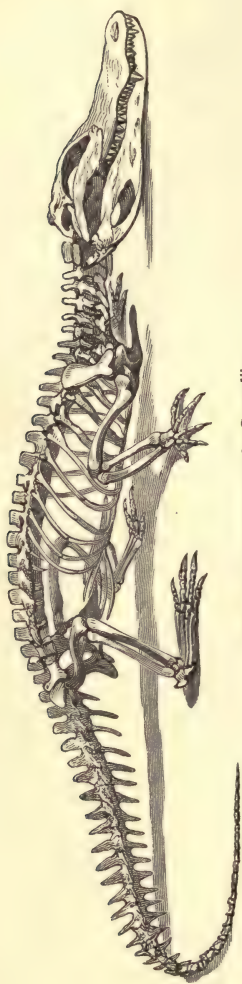


FIG. 310. — Skeletton of the Crocodile.



FIG. 311. — Skeletton of the Whalebone Whale (*Balena mysticetus*).

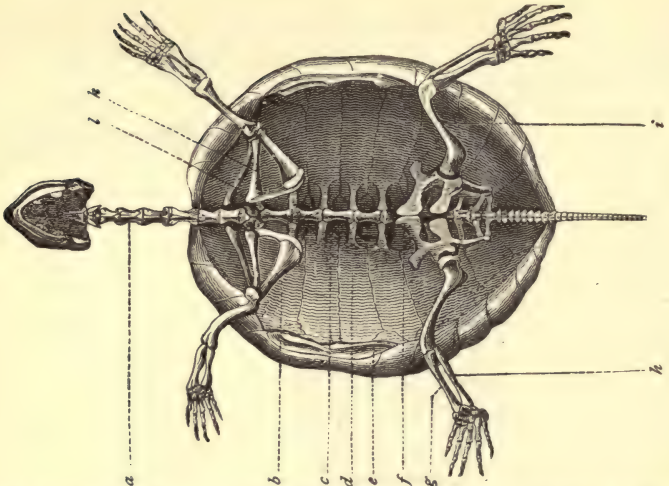


FIG. 312. — Skeleton of the Tortoise (plastron removed): *a*, cervical vertebræ; *c*, dorsal vertebræ; *d*, ribs; *e*, marginal bones of the carapace; *l*, scapula; *k*, precoracoid; *b*, coracoid; *f*, pelvis; *i*, femur; *g*, tibia; *h*, fibula.

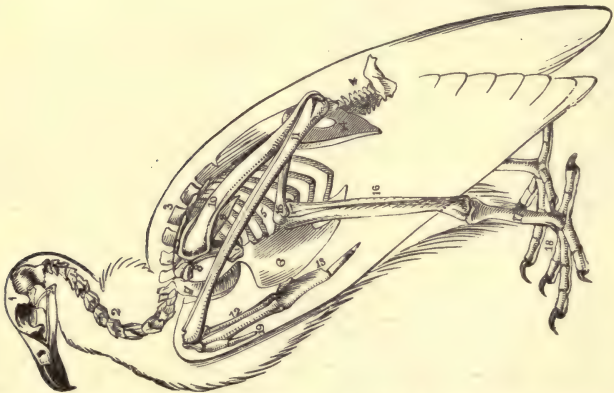


FIG. 313. — Skeleton of a Vulture: 1, cranium — the parts of which are separable only in the chick; 2, cervical vertebræ; 3, dorsal; 4, coccygeal, or caudal; the lumbar and sacral are consolidated; 5, ribs; 6, sternum, or breastbone, extraordinarily developed; 7, furculum, clavicle, or "wishbone"; 8, coracoid; 9, scapula; 10, humerus; 11, ulna, with rudimentary radius; 12, metacarpals; 13, phalanges of the great digit of the wing; 14, thumb; 15, pelvis; 16, femur; 16, tibiatarsus and fibula, or crus; 17, tarsometatarsus; 18, internal digit, or toe, formed of three phalanges; the middle toe has four phalanges; the outer, five; and the back toe, or thumb, two.

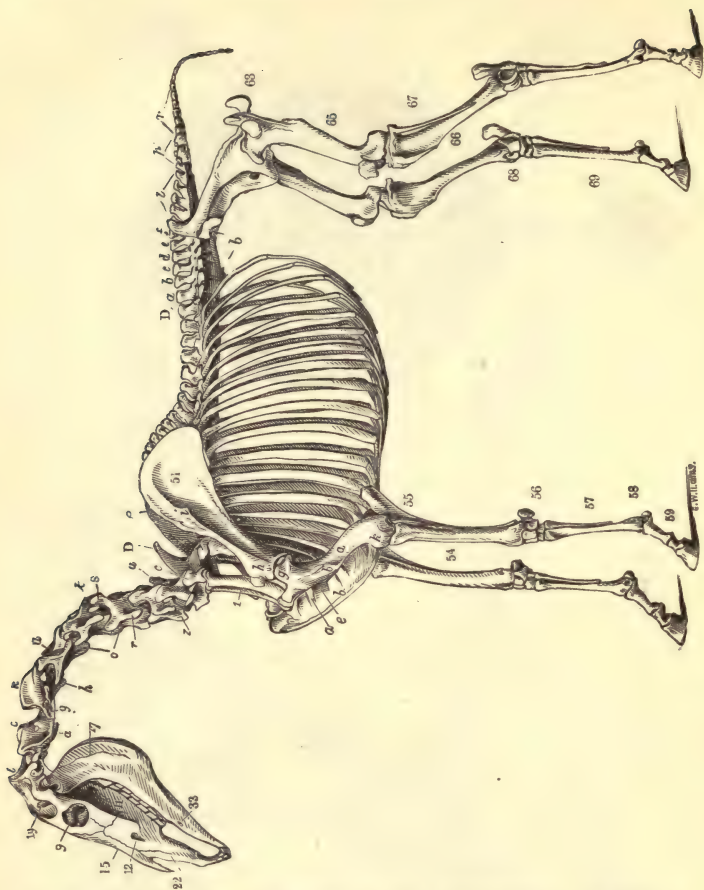
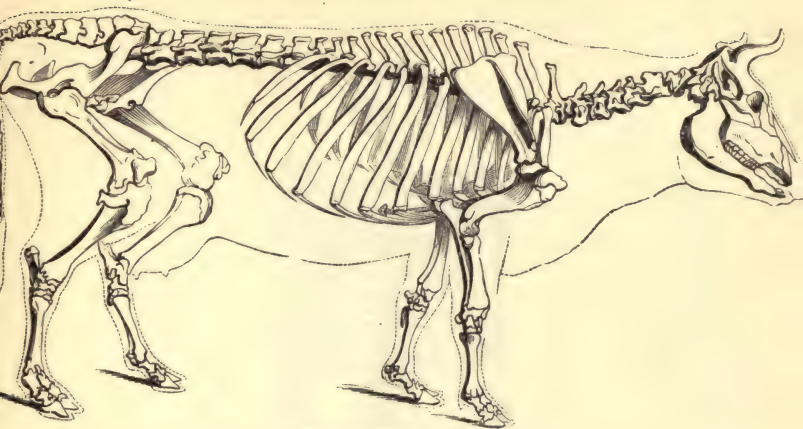
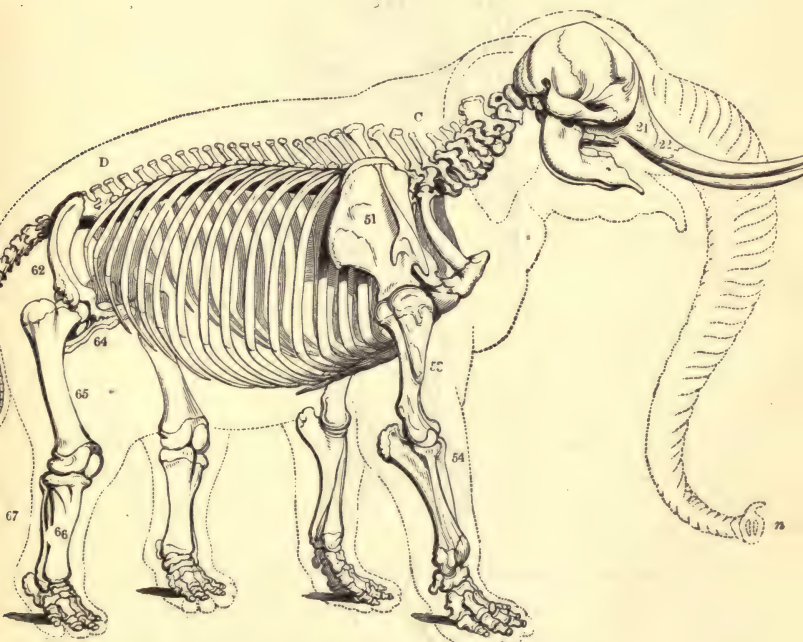


FIG. 314. — Skeleton of the Horse (*Equus caballus*): 22, premaxillary; 12, foramen in the maxillary; 15, nasal; 9, orbit; 19, coronoid process of lower jaw; 17, surface of implantation for the masseter muscle; there are seven cervical vertebræ, nineteen dorsal, D — D; five lumbar, a-e; five sacral, f-l; and seventeen caudal, p-r; 51, scapula, or shoulder blade; i, spine, or crest; h, coracoid process (acromion wanting); 1, first pair of ribs (clavicle wanting, as in all Ungulates); c, sternum; a, shaft of humerus; b, deltoid ridge; g, head fitting in the glenoid cavity of the scapula — near it is a great tuberosity for the attachment of a powerful muscle; k, condyles; 54, radius, to which is firmly ankylosed a rudimentary ulna, 55, the olecranon; 56, the seven bones of the carpus, or wrist; 57, large metacarpal, or “cannon bone,” with two “splint bones”; 58, fetlock joint; 59, phalanges of the developed digit, corresponding to the third finger in man; 62, pelvis; 63, the great trochanter, or prominence on the femur; 65; 66, tibia; 67, rudimentary fibula; 68, hock, or heel, falsely called knee; 69, metatarsals.

FIG. 315. — Skeleton of the Cow (*Bos taurus*).FIG. 316. — Skeleton of an Elephant (*Elephas indicus*).

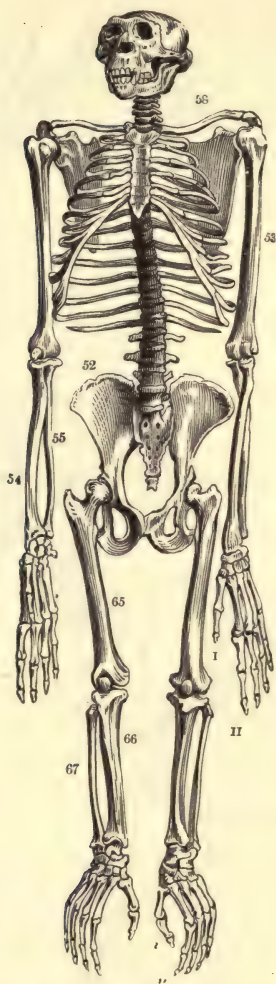


FIG. 317. — Skeleton of the Chimpanzee (*Anthropopithecus troglodytes*).

CHAPTER XX*

HOW ANIMALS MOVE

1. The power of animal motion is vested in protoplasm, cilia, and muscles. The power of contractility is one of the fundamental physiological properties of protoplasm, like sensibility and the power of assimilation. Protoplasmic animals, like the amœba and Rhizopoda (Figs. 1, 213), move by the contractility of their protoplasm, as also may the embryos of higher animals upon the yolk of the egg. Protoplasm may be extended into projections called *pseudopodia*, by whose contraction the animal may move.

Infusoria, and nearly all higher animals, possess *cilia* (Figs. 9, 11). These are short microscopic threads of protoplasm which have the power of bending into a sickle shape and straightening out. As they bend much faster than they straighten, and as they all work together, they can cause motion of the animal, or may serve to produce currents in the water, the animal remaining at rest. They are seen on the outside of Infusoria, and of embryos of very many higher animals, serving as paddles for locomotion; they line the channels in the gills of the oyster, creating currents for respiration; and they cover the walls of the passages to our lungs to expel the mucus. *Flagella* (Figs. 4, 5, 6) are a sort of long cilia, which are thrown into several curves when active, resembling a whiplash, whence their name. Both cilia and flagella seem to be wanting in arthropods.

* See Appendix.

The cause of ciliary motion is unknown. One-sided contraction is their property, as straight contraction is distinctive of the muscle fiber. No structure can, however, be seen in them with the microscope. No nerves go to them, yet they work in concert, waves of motion passing over a surface covered with cilia, as over a field of grain moved by the wind.



FIG. 318.—Waves of Contraction passing over a Muscular Fiber of Dytiscus.

I. Muscle. — Muscular tissue is the great motor agent, and exists in all animals from the coral to man.¹³³ The power of contractility, which in the amœba is diffused throughout the body, is here confined to bundles of highly elastic fibers, called *muscles*. When a muscle contracts, it tends to bring its two ends together, thus shortening itself, at the same time increasing in thickness. This shrinking property is excited by external stimulants, such as electricity, acids, alkalies, sudden heat or cold, and even a sharp blow; but the ordinary cause of contraction is an influence from the brain conveyed by a nerve. The property, however, is independent of the nervous system, for the muscle may be directly stimulated. The amount of force with which a muscle contracts depends on the number of its fibers; and the amount of shortening, on their length.

As a rule, muscles are white in cold-blooded animals, and red in the warm-blooded. They are white in all the invertebrates, fishes, batrachians, and reptiles, except salmon, sturgeon, and shark; and red in birds and mammals, except in the breast of the common fowl, and the like.¹³⁴



FIG. 319.—Unstriped Muscular Fiber, much enlarged; *n*, nucleus.

It is also a rule, with some exceptions, that the voluntary muscles of vertebrates, and all the muscles of the lobster, spider, and insect tribes, are striated; while the involuntary muscles of vertebrates, and all the muscles of radiates, worms, and mollusks, are smooth. All muscles attached to internal bones, or to a jointed external skeleton, are striated. The voluntary muscles of vertebrates are generally solid, and the involuntary surround cavities.¹³⁵

This leads to another classification of muscles: into those which are attached to solid parts within the body; those which are attached to the skin or its modifications; and those having no attachments, being complete in themselves. The last are hollow or circular muscles, inclosing a cavity or space, which they reduce by contraction. Examples of such are seen in the heart, blood vessels, stomach, iris of the eye, and around the mouth. In the lower invertebrates, the muscular system is a network of longitudinal, transverse, and oblique fibers intimately blended with the skin, and not divisible into separate muscles. As in the walls of the human stomach, the fibers are usually in distinct layers. This arrangement is exhibited by soft-bodied animals, like the sea anemone, the snail, and the earthworm. Four thousand muscles have been counted in a caterpillar. There are also "skin muscles" in the higher animals, as those by which the horse produces a twitching of the skin to shake off insects, and those by which the hairs of the head and the feathers of birds are made to stand on end. Invertebrates whose skin is hardened into a shell or crust have muscles attached to the inside of such a skeleton. Thus, the oyster has a mass of parallel fibers connecting its two valves; while in the lobster and bee fibers go from ring to ring, both longitudinally and spirally. The muscles of all invertebrates are

straight parallel fibers, not in bundles, but distinct, and usually flat, thin, and soft.

The great majority of the muscles of vertebrates are attached to the bones, and such are voluntary. The fibers, which are coarsest in fishes (most of all in the rays), and finest in birds, are bound into bundles by connective tissue; and the muscles thus made up are arranged in layers around the skeleton. Sometimes their extremities are attached to the bones (or rather to the *periosteum*) directly; but generally by means of white inelastic cords, called *tendons*. In fishes, the chief masses of muscle are disposed along the sides of the body, apparently in longitudinal bands, reaching from head to tail, but really in a series of vertical flakes, one for each vertebra. In proportion as limbs are developed, we find the muscles concentrated about the shoulders and hips, as in quadrupeds. The bones of the limbs are used as levers in locomotion, the fulcrum being the end of a bone with which the moving one is articulated. Thus, in raising the arm, the humerus is a lever working upon the scapula as a fulcrum. The most important muscles are called *extensors* and *flexors*. The latter are such as bring a bone into an angle with its fulcrum — as in bending the arm — while the former straighten the limb. *Abductors* draw a limb away from the middle line of the body, or a finger or toe away from the axis of the limb, while *adductors* bring them back.

2. Locomotion. — All animals have the power of voluntary motion, and all, at one time or another, have the means of moving themselves from place to place. Some are free in the embryo life, and fixed when adult, as the sponge, coral, crinoid, and oyster. There may be no regular, well-defined means of progression, as in the amœba, which extemporizes arms to creep over the sur-

face; or movement may be accomplished by the contraction of the whole body, as in the jellyfish, which, pulsating about fifteen times in a minute, propels itself through the water. So the worms and snakes swim by the undulations of the body.

But as a rule, animals are provided with special organs for locomotion. These become reduced in number, and progressively perfected, as we advance in the scale of rank. Thus, the infusorian is covered with thousands of hairlike cilia; the starfish has hundreds of soft, unjointed, tubular suckers; the centipede has from 30 to 40 jointed hollow legs; the lobster, 10; the spider, 8; and the insect, 6; the quadruped has 4 solid limbs for locomotion; and man, only 2.

(1) **Locomotion in Water.** — As only the lower forms of life are aquatic, and as the weight of the body is partly sustained by the element, we must expect to find the or-

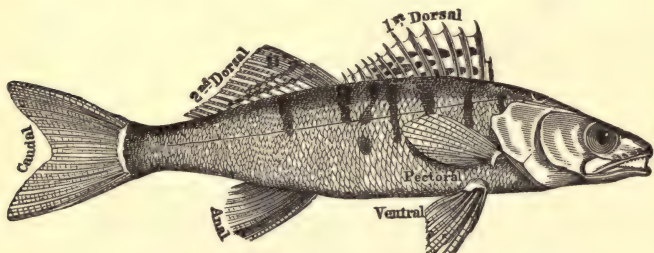


FIG. 320. — The Fins of a Fish (*Pike Perch*).

gans of progression simple and feeble. The Infusoria swim with great rapidity by the incessant vibrations of the delicate filaments, or cilia, on their bodies. The common squid on our coast admits water into the interior of the body, and then suddenly forces it out through a funnel, and thus moves backward, or forward, or around, according as the funnel is turned — toward the head, or tail, or to one side. The lobster has a fin at

the end of its tail, and propels itself backward by a quick downward and forward stroke of the abdomen.

But fishes, whose bodies offer the least resistance to progression through water, are the most perfect swimmers. Thus, the salmon can go twenty miles an hour, and even ascend cataracts. They have fins of two kinds: those set obliquely to the body, and in pairs; and those which are vertical, and single. The former,



FIG. 321. — Diagram illustrating the locomotion of a Fish. The tail describes the arc of an ellipse; the resultant of the two impulses is the straight line in front.

called *pectoral* and *ventral* fins, represent the fore and hind limbs of quadrupeds. The vertical fins, which are only expansions of the skin, vary in number; but in most fishes there are at least three: the *caudal*, or tail fin; the *dorsal*, or back fin; and the *anal*, situated on the abdomen, near the tail. The chief locomotive agent is the tail, which sculls like a stern oar; the other fins are mainly used to balance and raise the body.

When the two lobes of the tail are equal, and the vertebral column stops near its base, as in the trout, it is said to be *homocercal*. If the vertebræ extend into the upper lobe, making it longer than the lower one, as in the shark, the tail is called *heterocercal*. The latter is the more effective for varying the course; the shark, *e.g.*, will accompany and gambol around a ship in full sail across the Atlantic. The whale swims by striking the water up and down, instead of laterally, with a finlike horizontal tail. Many air-breathing animals swim with facility on the surface, as the water birds, having webbed toes, and most of the reptiles and quadrupeds.

(2) **Locomotion in Air.** — The power of flight requires a special modification of structure and an extraordinary muscular effort, for air is 800 times lighter than water. Nevertheless, the velocity attainable by certain birds is greater than that of any fish or quadruped; the hawk being able to go at the rate of 150 miles an hour. The bodies of insects and birds are made as light as possible by the distribution of air sacs or air cavities.¹³⁶

The wings of insects are generally four in number; sometimes only two, as in the fly. They are moved by muscles lying inside the thorax. They are simple expansions of the skin, or crust, being composed of two delicate films of the epidermis stretched upon a network of tubes. There are three main varieties: thin and transparent, as in the dragon fly; opaque, and covered with minute colored scales, which are in reality flattened hairs, as in the butterfly; and hard and opaque, as the first pair (called *elytra*) of the beetle.

The wings of birds, on the other hand, are modified fore limbs, consisting of three sets of feathers (called



FIG. 322. — Flamingoes taking Wing.

primary, secondary, and tertiary), inserted on the hand, forearm, and arm. The muscles which give the downward stroke of the wing are fastened to the breastbone;

and their power, in proportion to the weight of the bird, is very great. Yet the insect is even superior in vigor and velocity of flight.¹³⁷ In ascending, the bird slightly rotates the wing, striking downward and a little backward ; while the tail acts as a rudder. A short, rounded, concave wing, as in the common fowl, is not so well fitted for high and prolonged flight as the long, broad, pointed, and flat wing of the eagle. The wing is folded by means of an elastic skin and muscle connecting the shoulder and wrist. Besides insects and birds, a few other animals have the power of flight, as bats, by means of long webbed fingers ; flying fishes, by large pectoral fins. Flying reptiles, flying squirrels, and the like, have a membrane stretched on the long ribs, or connecting the fore and hind limbs, which they use as a parachute, enabling them to take very long leaps.

(3) **Locomotion on Solids.** — This requires less muscular effort than swimming or flying. The more unyielding the basis of support, the greater the amount of power left to move the animal along. The simplest method is



FIG. 323. — Diagrammatic Section of the Disk and one Ray of Starfish: *a*, mouth; *b*, stomach; *c*, hepatic cæcum; *d*, dorsal or aboral surface; *e*, ambulacral plates; *f*, ovary; *g*, tubular feet; *h*, internal sacs for distending the feet.

the suctorial, the animal attaching itself to some fixed object, and then, by contraction, dragging the body onward. But the higher and more common method is by the use of bones, or other hard parts, as levers.

The starfish creeps by the working of hundreds of tubular suckers, which are extended by being filled with fluid forced into them by little sacs. The clam moves by fixing and contracting a muscular appendage, called a "foot." The snail has innumerable short muscles on the under side of its body, which, by successive contractions, resembling minute undulations, enable the animal to glide forward apparently without effort. The leech has a sucker at each end; fixing itself by the one on its tail, and then stretching the body, by contracting the muscular fibers which run around it, the creature fastens its mouth by suction, and draws forward the hinder parts by the contraction of longitudinal muscles. The earthworm lengthens and shortens itself in the same way as the leech, but instead of suckers for holding its position, it has numerous minute spines which may be pointed backward or forward; while the caterpillar has short legs for the same purpose. The legless serpent moves by means of the scutes, or large scales on the under side of the body, acted upon by the ribs. In a straight line, locomotion is slow; but by curving the body, laterally or vertically, it can glide or leap with great rapidity.

Most animals have movable jointed limbs, acted upon as levers by numerous muscles. The centipede has forty-two legs, each with five joints and a claw. The crab has five pairs of six-jointed legs; but the front pair is modified into pincers for prehension. With the rest, which end in a sharp claw, the crab moves backward, forward, or sideways. The spider has eight legs, usually seven-jointed, and terminating in two claws toothed like a comb, and a third which acts like a thumb. In running, it moves the first right leg, then the fourth left; next, the first left, and then the fourth right; then the third right and second left together;

and lastly, the third left and second right together. The front and hind pairs are, therefore, moved like those of a quadruped. The insect has six legs, each of five parts: the *coxa*; *trochanter*; *femur*; *tibia*, or

shank; and *tarsus*.

The last is subdivided usually into five joints and a pair of claws. Such as can walk upside down, as the fly, have, in addition, two or three pads between the claws.¹³⁸ These pads bear hairs which secrete a sticky fluid by means of which the fly adheres to the surface. While the leg bones of vertebrates are



FIG. 324. — Feet of Insects, magnified: A, *Bibio febrilis*; B, House Fly (*Musca domestica*); C, Water Beetle (*Dytiscus*).

covered by the muscles which move them, the limbs of insects are hollow, and the muscles inside. The fore legs are directed forward, and the two hinder pairs backward. In motion, the fore and hind feet on one side, and the middle one on the other, are moved simultaneously, and then the remaining three.

The four-legged animals have essentially the same apparatus and method of motion. The crocodile has an awkward gait, owing to the fact that the limbs are short, and placed far apart, so that the muscles act at a mechanical disadvantage. The tortoise is proverbially slow, for a similar reason. Both swim better than they

walk. Lizards are light and agile, but progression is aided by a wriggling of the body.

The locomotive organs of the mammalian quadrupeds are much more highly organized. The bones are more compact; the vertebral column is arched and yet elastic, between the shoulder and hip, and the limbs are placed vertically underneath the body. The bones of the fore limb are nearly in a line; but those of the hind limb, which is mainly used to project the body forward, are more or less inclined to one another, the angle being

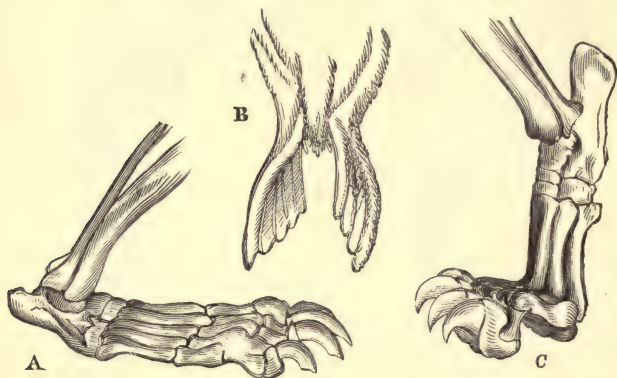


FIG. 325. — Feet of Carnivores: A, Plantigrade (*Bear*); B, Pinnigrade (*Seal*); C, Digitigrade (*Lion*).

most marked in animals of great speed, as the horse. Some walk on hoofs, as the ox (ungulate); some on the toes, as the cat (digitigrade); others on the sole, touching the ground with the heel, as the bear (plantigrade). In the pinnigrade seal, half of the fore limb is buried under the skin, and the hind limbs are turned backward to form a fin with the tail. The normal number of toes is five; but some may be wanting, so that we have one-toed animals (as horse), two-toed (as ox), three-toed (as rhinoceros), four-toed (as hippopotamus), and five-toed

(as the elephant). The horse steps on what corresponds to the nail of the middle finger; and its swiftness is conditioned on the solidity of the extremities of the

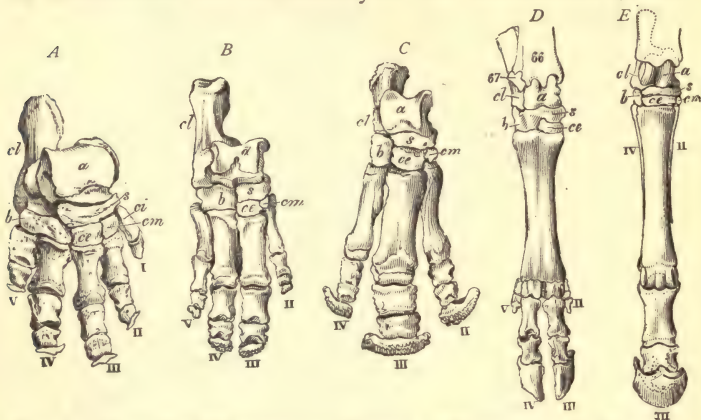


FIG. 326. — Feet of Hoofed Mammals: *A*, Elephant; *B*, Hippopotamus; *C*, Rhinoceros; *D*, Ox; *E*, Horse. *a*, astragalus; *cl*, calcaneum, or heel; *s*, navicular; *b*, cuboides; *ce*, *ci*, *cm*, cuneiform bones; the numbers indicate the digits in use.

limbs. Horses of the greatest speed have the shoulder joints directed at a considerable angle with the arm.

The order in which the legs of quadrupeds succeed each other determines the various modes of progression, called the walk, trot, gallop, and leap. Many, as the horse, have all these movements; while some only leap, as the frog and kangaroo. In leaping animals, the hind limbs are extraordinarily developed. In many mammals, like the squirrel, cat, and dog, the fore legs are used for prehension as well as locomotion. Monkeys use all four, and also the tail, for locomotion and prehension, keeping a horizontal attitude; while the apes, half erect, as if they were half quadruped, half biped, go shambling along, touching the ground with the knuckles of one hand and then of the other. In descending the scale, from the most anthropoid ape to the true quadruped, we find the center of gravity placed increasingly higher up

— that is, farther forward. Birds and men are the only true bipeds, the former standing on their toes, the latter

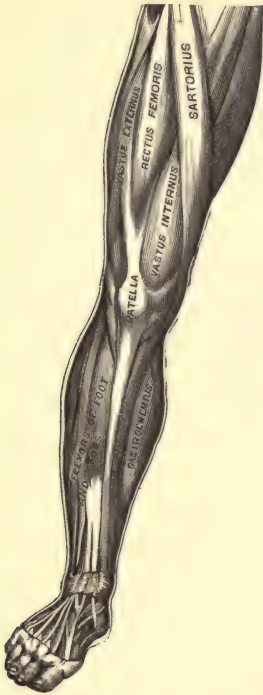


FIG. 327. — Muscles of the Human Leg: *sartorius*, or "tailor's muscle," the longest muscle in the body, flexes the leg upon the thigh: *rectus femoris* and *vastus externus* and *internus* extend the leg, maintaining an erect posture; *gastrocnemius*, or "calf," used chiefly in walking, for raising the heel. Another layer underlies these superficial muscles.



FIG. 328. — Muscles of an Insect's Leg (*Melolontha vulgaris*): *a*, flexor, and *b*, extensor, of tibia; *c*, flexor of foot; *d*, accessory muscle; *e*, extensor of claw; *f*, extensor of tarsus. The joints are restricted to movements in one plane; and therefore the muscles are simply flexors and extensors. All the muscles are *within* the skeleton.

on the soles of the feet. Terrestrial birds walk and run; while birds of flight usually hop. The ostrich can for a time outrun the Arabian horse; and the speed of the cassowary exceeds that of the swiftest greyhound.

CHAPTER XXI *

THE NERVOUS SYSTEM

Nerve Tissue exists in the form of cells and fibers, the latter being prolongations of the bodies of the former. Where the cells predominate, nerve tissue is grayish. Such accumulations are called *ganglia*, or *nerve centers*, and these alone originate nervous force; the fibers are generally white, and arranged in bundles, called



FIG. 329.—Nerve cell from cerebral cortex :
n, nerve process.

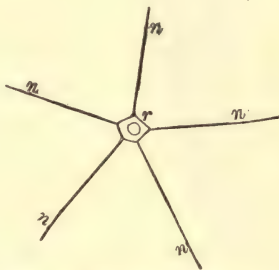


FIG. 330.—Diagram of Nervous System of Starfish: *r*, nervous ring around mouth; *n*, radial nerves to each arm, ending in the eye.

nerves, which serve only as conductors. Most nerves contain two kinds of fibers, like in structure, but each having its distinct office: one carries impressions received from the external world to the gray centers, and hence is called an *afferent*, or *sensory*, nerve; the other conducts an influence generated in the center to the muscles, in obedience to which they

* See Appendix.

contract, and hence it is called an *efferent*, or *motor*, nerve. Thus, when the finger is pricked with a pin, afferent nerve fibers convey the impression to the center, the spinal cord, which immediately transmits an order by efferent fibers to the muscles of the hand to contract. If the former are cut, sensation is lost, but voluntary motion remains; if the latter are cut, the animal loses all control over the muscles, although sensibility is perfect; if both are cut, the animal is said to be paralyzed in the parts which these nerves control. The nerve fibers are connected with nerve cells in the central organs, and at the outer ends are connected with the muscular fibers, or with various sensory end organs in the skin or other parts of the body. The nature of nerve force is not known.

As to the velocity of a nervous impulse, we know it is far less than that of electricity or light, and that it is more rapid in warm-blooded than in cold-blooded animals, being faster in man than in the frog. In the latter it averages about 85 feet per second, the former over 100 feet.

The very lowest animals, like the amœba and Infusoria, have no nerves, although their protoplasm has a general sensibility. The hydra has certain cells which are, perhaps, partly nervous and partly muscular in function. The jellyfish has a nervous system, consisting of a network of threads and ganglia scattered all over its disk. We should look for a definite system of ganglia and nerves only in those animals which possess

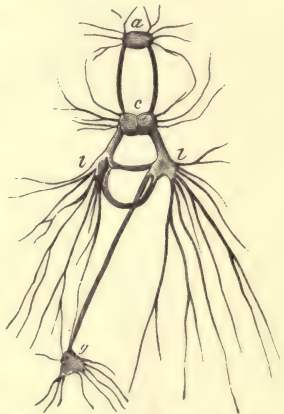


FIG. 331.—Nervous System of a Mollusk (the Gastropod *Aplysia*): *a*, anterior ganglion; *c*, cephalic; *l*, lateral; *g*, abdominal.

a definite muscular structure, and show definitely coördinated muscular movements. In the starfish we detect the first clear specimen of such a system. It consists of a ring around the mouth, made of five ganglia of equal size, with radiating nerves. The mollusks are distinguished by an irregularly scattered nervous system. The clam has three main pairs of connected ganglia — one near the mouth, one in the foot, and the third in the posterior region, near the siphons.

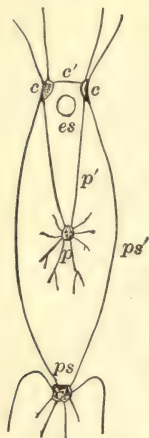


FIG. 332. — Nervous System of Clam; *c*, cerebral ganglion; *p*, pedal ganglia; *ps*, parietosplanchnic ganglia; *c'*, cerebral commissure; *p'*, commissure from cerebral to pedal ganglia; *ps'*, commissure from cerebral to parietosplanchnic ganglia; *es*, esophagus.

In the snail, these are united into a ring around the gullet, and there are other ganglia scattered through the body. The same is true of the cuttlefish, where the brain is partly inclosed in a cartilaginous box (Fig. 348). In the simpler worms there is but a single ganglion or a single pair. The earthworm has a pair of brain ganglia lying above the gullet, and connected by two cords with a ventral chain of ganglia — one pair, apparently a single ganglion, for each segment. In the lower arthropods, such as Crustacea, centipedes, and larval insects, the arrangement is substantially the same. In higher insects and Crustacea, many of the ganglia are fused together in the head and thorax, indicating a concentration of organs for sensation and locomotion.



FIG. 333. — Nervous System of a Caterpillar (*Sphinx ligustri*): the first is the cephalic, or head, ganglion.

In vertebrates, the nervous system is more highly developed, more complex, and more concentrated than in the lower forms. In fact, there are some parts, as the brain, to which we find nothing homologous in the invertebrates; and while the actions of the latter are mainly, if not wholly, automatic, those of backboned animals are largely voluntary. Its position, moreover, is peculiar, the great mass of the nervous matter being accumulated on the dorsal side, and inclosed by the neural arches of the skeleton.

The brain and spinal cord lie in the cavity of the skull and spinal column, wrapped in three membranes. Each consists of gray and white nervous matter; but in the brain the gray is on the outside, and the white within; while the white of the spinal cord is external, and the gray internal. Both are double, a deep fissure running from the forehead backward, dividing the brain into two hemispheres, and the spinal cord resembling two columns welded together; even the nerves come forth in pairs to the right and left. The brain is

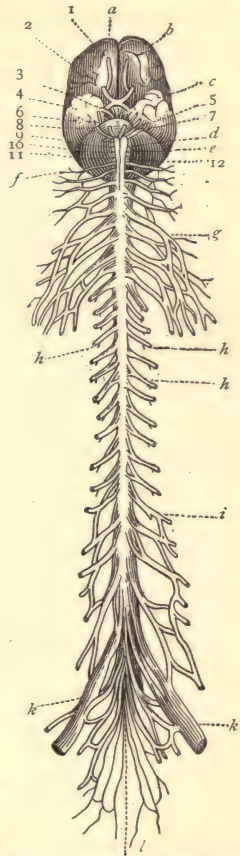


FIG. 334. — Human Brain and Spinal Cord, seen from below, about one-tenth natural size; *a*, right hemisphere of cerebrum; *b*, anterior lobe; *c*, middle lobe; *d*, medulla oblongata; *e*, cerebellum; *f*, first spinal nerve; *g*, brachial plexus of nerves supplying the arms; *h*, dorsal nerves; *i*, lumbar nerves; *k*, sacral plexus of nerves for the limbs; *l*, cauda equina: the figures indicate the twelve pairs of cranial nerves, of which 1 is olfactory, 2 optic, and 8 auditory.

the organ of sensation and voluntary motion ; the spinal cord is the organ of involuntary life and motion. The brain, above the medulla oblongata, may be removed, and yet the animal, though it cannot feel, will live for a time, showing that it is not absolutely essential to life ; in fact, the brain does nothing in apoplexy and deep sleep. All of the cord, except that part containing the centers for respiration and circulation, may also be destroyed, without causing immediate death.

The Brain is that part of the nervous system contained in the skull.¹³⁹ It increases in size and complexity as we pass from the fishes, by the amphibians, reptiles, and birds, to mammals. Thus the body of the cod is 5000 times heavier than its brain—in fact, the brain weighs less than the spinal cord ; while in man, the brain, compared with the body, is as 1 to 36, and is 40 times heavier than the spinal cord. The brains of the cat weigh only 1 oz. ; of the dog, 6 oz. 5½ dr. ; and of the horse, 22 oz. 15 dr. The only animals whose brains outweigh man's are the elephant and whale—the maximum weight of the elephant's being 10 lbs., and of the whale's 5 lbs. ; while the human does not exceed 4 lbs. Yet the human brain is heavier in proportion to the body. But quality must be considered as well as quantity, else the donkey will outrank the horse, and the canary bird, man ; for their brains are relatively heavier.

The main parts of the brain are the *cerebrum*, *cerebellum*, and *medulla oblongata*.

The cerebrum is a mass of white fibrous matter covered by a layer of gray cellular matter. In the lower vertebrates, the exterior is smooth ; but in most of the mammals it is convoluted, or folded, to increase the amount of the gray surface. The convolutions multiply and deepen as we ascend the scale of size and intelli-

gence, being very complex in the elephant and whale, monkey and man. As a rule, they are proportioned to the intelligence of the animal; yet the brains of the dog and horse are smoother than those of the sheep and donkey. Evidently the quality of the gray matter must be taken into account. Save in the bony fishes, the cerebrum is the largest portion of the brain; in man it is over eight times heavier than the cerebellum.

The cerebellum, or "little brain," lies behind the cerebrum, and, like it, presents an external gray layer, with a white interior. In mammals, it is likewise finely convoluted, consisting of gray and white laminæ, and is divided into two lobes, or hemispheres. In the rest of the vertebrates, the cerebellum is nearly or quite smooth; and in the lowest fishes it is merely a thin plate of nervous matter. In many vertebrates, however, it is larger compared with the cerebrum, than in man, since in man the cerebrum is extraordinarily developed.

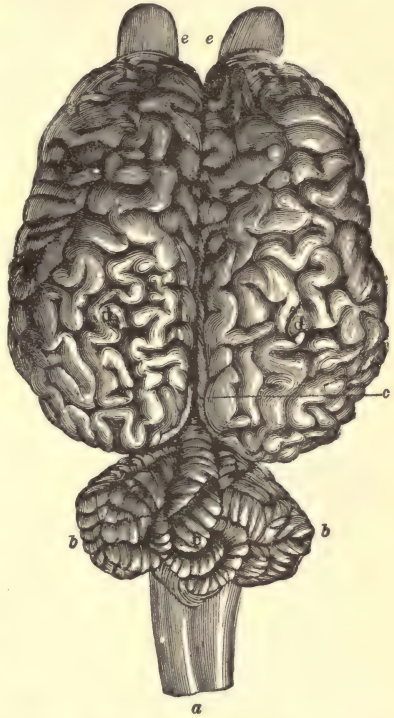


FIG. 335. — Brain of the Horse — upper view, one fourth natural size; *a*, medulla oblongata; *b*, lateral and middle lobes of cerebellum; *c*, interlobular fissure; *d*, cerebral hemispheres; *e*, olfactory lobes.

The medulla oblongata is the connecting link between the cerebrum and cerebellum and the spinal cord. In structure, it resembles the spinal cord—the white matter being external and the gray internal. The former lies beneath or behind the brain, passing through the *foramen magnum* of the skull, and merging imperceptibly into the cord. The latter is a continuous tract of gray matter inclosed within strands of white fibers. It usually ends in the lumbar region of the vertebral column, but in fishes it reaches to the end of the tail. In fishes, amphibians, and reptiles, the cord outweighs the brain; in birds and mammals, the brain is heavier than the cord. In man, the cord weighs about an ounce and a half.



FIG. 336. — Brain of the Perch, upper view: *a*, cerebellum; *b*, optic lobes; *c*, cerebrum; *i*, olfactory lobes; *g*, medulla oblongata.

Besides these parts, there are also the olfactory and the optic lobes, which give rise respectively to the nerves of smell and sight.

The parts of the brain are always in pairs; but in relative development and position they differ widely in the several classes of vertebrates.

In fishes and reptiles, they are arranged in a horizontal line; in birds

and mammals, the axis of the spinal cord bends to nearly a right angle in passing through the brain, so that the lobes no longer lie in a straight line.

In man, the fore brain is so developed that it covers all the other lobes. In looking down upon the brain of a

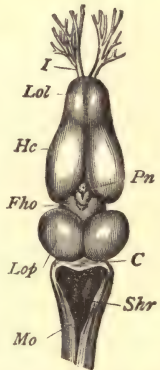


FIG. 337. — Brain of the Frog, upper view; $\times 4$: *I*, olfactory nerves; *Lol*, olfactory lobes; *Hc*, cerebral hemispheres; *Pn*, pineal gland; *Fho* and *Shr*, third and fourth ventricles; *Lop*, optic lobes; *C*, cerebellum; *Mo*, medulla oblongata.

perch, we see in front a pair of olfactory lobes (which send forth the nerves of smell), behind them the small cerebral hemispheres, then the large optic lobes (near which originate the nerves of sight), and, last of all, the cerebellum. Not until we reach man and the apes do we find the cerebrum so highly developed as to overlap both the olfactory lobes in front and the cerebellum behind.

Functions of the Brain. — The cerebrum is the seat of intelligence and will. It has no direct communication with the outside world, receiving its consciousness of external objects and events through the spinal cord and the nerves of special sense.¹⁴⁰

The cerebellum seems to preside over the coördination of the muscular movements. When the cerebellum

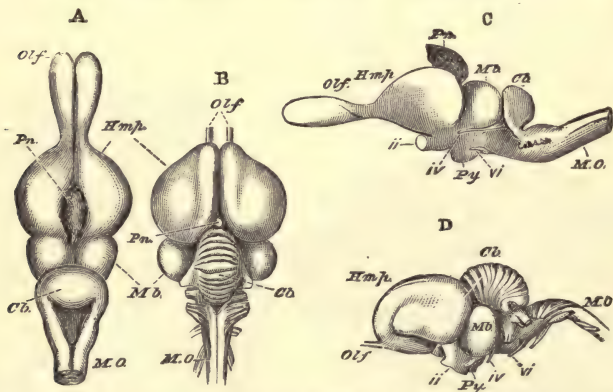


FIG. 338. — A, C, upper and side views of the Brain of a Lizard ; B, D, upper and side views of the Brain of a Turkey: *Olf*, olfactory lobes ; *Hmp*, cerebral hemispheres ; *Pn*, pineal gland ; *Mb*, optic lobes of the middle brain ; *Cb*, cerebellum ; *MO*, medulla oblongata ; *ii*, optic nerves ; *iv* and *vi*, nerves for the muscles of the eye ; *Py*, pituitary body.

is removed, the animal desires to execute the mandates of the will, but can not ; its motions are irregular, and it acts as if intoxicated. It is usually largest in animals capable of the most complicated movements, being

larger in the ape than in the lion, in the lion than in the ox, in birds than in reptiles. The cerebellum of the

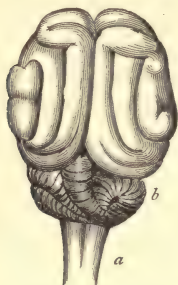


FIG. 339. — Brain of the Cat (*Felis domestica*): *a*, medulla oblongata; *b*, cerebellum; *c*, cerebrum.

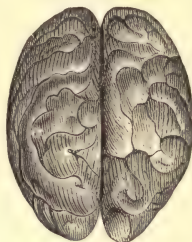


FIG. 340. — Brain of the Orang-outang upper surface; one third natural size.

frog is, however, smaller than that of fishes (Figs. 336, 337). The olfactory and optic lobes receive the messages from their respective nerves. The medulla oblongata is not only the medium of communication between the brain and the spinal cord,



FIG. 341. — Human Brain, side view: 1, medulla oblongata; 3, cerebellum; 5, frontal convolutions of cerebrum.

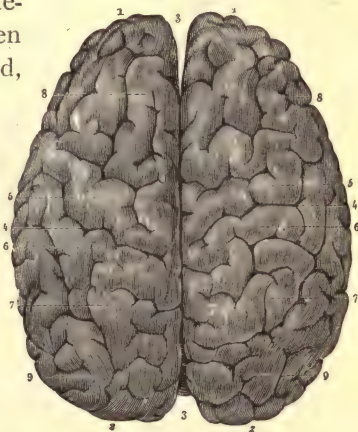


FIG. 342. — Human Brain, upper view, one fourth natural size: 1, anterior lobes; 2, posterior; 3, great median fissure.

but it is itself a nervous center: the brain above and the cord below may be removed without death to the

animal, but the destruction of the medulla is fatal. Of the twelve pairs of nerves issuing from the contents of the skull (*encephalon*), ten come from the medulla oblongata. Among these are the nerves of hearing and taste, and those that control the lungs and heart. Respiration ceases immediately when the medulla is injured.

The spinal cord is a center for originating involuntary actions, and is also a conductor — transmitting through its cells and fibers to the brain the impressions received by the sensory organs, and taking back to the motor organs the impulses of the brain. In man, thirty-one pairs of nerves arise from the cord to supply the whole body, except the head. Each nerve has an anterior and a posterior root. The fibers of the former go to the muscles, and carry the impulses which cause muscular contraction (hence called *motor fibers*); those of the posterior root convey sensations from the exterior to the central organs (*sensory*). The fibers leading from the brain to the cord cross one another in the medulla oblongata, so that if the right cerebral hemisphere be



Fig. 343. — Relation of the Sympathetic and Spinal Nerves : *c*, fissure of spinal cord; *a*, anterior root of a dorsal spinal nerve; *p*, posterior root, with its ganglion; *a'*, anterior branch; *p'*, posterior branch; *s*, sympathetic; *e*, its double junction by nerve filaments.

diseased, the left side of the body loses the power of voluntary motion.

The *sympathetic nervous system* is a double chain of ganglia, lying along the sides of the vertebral column in the ventral cavity. From these ganglia nerves are given off, which, instead of going to the skin and muscles, like the spinal nerves, form networks about those internal organs over which the will has no control, as the heart, stomach, and intestines. Apparently their office is to stimulate these organs to constant activity, but is little understood.

1. *The Senses*

Sensation is the consciousness of impressions on the sensory organs. These impressions produce some change in the brain; but what that change is, is a darkness on which no hypothesis throws light. Obviously, we feel only the condition of our nervous system, not the objects which excite that condition.¹⁴¹

All animals possess a general sensibility diffused over the greater part of the body.¹⁴² This sensibility, like assimilation and contractility, is one of the primary physiological properties of protoplasm. But, besides this (save in the very lowest forms), they are endowed with special nerves for receiving the impressions of light, sound, etc. These nerves of sense, as they are called, although structurally alike, transmit different sensations: thus, the ear can not recognize light, and the eye can not distinguish sounds. In the vertebrates, the organs of sight, hearing, and smell are situated in pairs on each side of the head; that of taste, in the mucous membrane covering the tongue; while the sense of touch and that of temperature are diffused over the skin, including the mucous membrane of the mouth, throat, and nose.

Sight and hearing are stimulated, each by one agent only; while touch, taste, and smell may be excited by various substances. The agents awakening sight, hearing, touch, and the sense of temperature are physical; those causing taste and smell are chemical. Animals differ widely in the numbers and keenness of their senses. But there is no sense in any one which does not exist in some other.

Touch is the simplest and the most general sense; no animal is without it, at least in the form of general sensibility. It is likewise the most positive and certain of the senses. In the sea anemone, snail, and insect, it is most acute in the "feelers" (tentacles, horns, and antennæ);¹⁴³ in the oyster, the edge of the mantle is most sensitive; in fishes, the lips; in snakes, the tongue; in birds, the beak and under side of the toes; in quadrupeds, the lips and tongue; and in monkeys and man, the lips and the tips of the tongue and fingers. In the most sensitive parts of birds and mammals, the true skin is raised up into

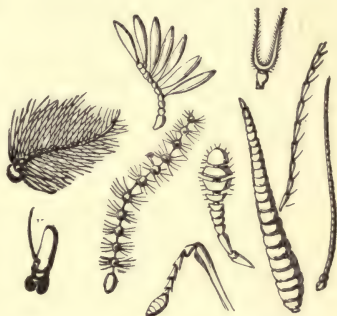


FIG. 344. — Antennæ of various Insects (magnified).

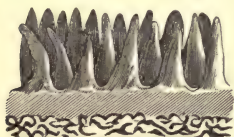


FIG. 345. — Papillæ of Human Palm, $\times 35$, the cuticle being removed.

multitudes of minute elevations, called *papillæ*, containing loops of capillaries and nerve filaments. At the ends of the latter are the essential organs of touch, the *tactile corpuscles* and the *touch cells*.

There is a correspondence between the delicacy of touch and the development of intelligence. The cat and dog are more sagacious than

hoofed animals. The elephant and parrot are remarkably intelligent, and are as celebrated for their tactual power.

Taste is more refined than touch, since it gives a knowledge of properties which can not be felt. It is always placed at the entrance to the digestive canal, as its chief purpose is to guide animals in their choice of food. Special organs of taste have been detected in only a few of the invertebrates, though all seem to exercise a faculty in selecting their food. Even in fishes, amphibians, reptiles, and birds this sense is very obtuse, for they bolt their food. But the higher vertebrates have it well developed. It is confined to the tongue, and is most delicate at the root.¹⁴⁴ A state of solution and an actual contact of the fluid are necessary conditions.

Smell is the perception of odors, *i.e.*, certain substances in the gaseous or volatile state. Many invertebrates have this sense: snails, *e.g.*, seem to be guided to their food



FIG. 346. — Olfactory Nerves on the wall of the nasal cavity.

by its scent, and flies soon find a piece of meat. In the latter the organ is probably located on the antennæ. In vertebrates, it is placed at the entrance to the respiratory tube, in the upper region of the nose.

There the olfactory nerves, which issue from the olfactory lobe of the brain, and pass through the ethmoid bone, or roof of the nasal cavity, are distributed over a moist mucous membrane. The odorous substance, in a gaseous or finely divided state, is dissolved in the mucus covering this membrane. In fishes and reptiles generally, this organ is feebly developed; sharks, however, gather from a great distance around a carcass. In the porpoises and whales it is nearly or entirely wanting. Among birds,

waders have the largest olfactory nerves. It is most acute in the carnivorous quadrupeds, and in some wild herbivores, as the deer. In man it is less delicate, but has a wider range than in any brute.

Hearing is the perception of sound. The simplest form of the organ is a sac filled with fluid, in which float the soft and delicate ends of the auditory nerve. Usually the vibrations of the fluid are strengthened by the presence of minute hard granules, called *otoliths*. Most invertebrates have no more complicated apparatus than this; and it is probable that they can distinguish one noise from another, but neither pitch nor intensity.



FIG. 347. — Ear of a Mollusk (*Cyclas*), greatly enlarged, showing the otolith in the center of a cavity which is filled with fluid, and whose walls are lined by ciliated cells.

The organ is generally double, but not always located in the head. In the clam, it is found at the base of the foot; some grasshoppers have it in the fore legs; and in many insects it is on the wing. Lobsters and crabs have the auditory sacs at the base of the antennæ.¹⁴⁵

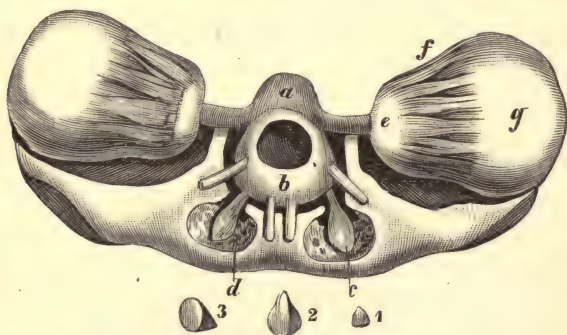


FIG. 348. — Brain and Auditory Apparatus of the Cuttlefish: *a*, *b*, brain; *c*, auditory apparatus; *d*, the cavity in which it is lodged; *e*, *f*, *g*, eyes; 1, 2, 3, otoliths.

A complex organ of hearing, located in the head, exists in all vertebrates, save the very lowest fishes.

As complete in man, it consists of the following parts :

1. The external ear (which is peculiar to mammals ¹⁴⁶); the auditory canal, about an inch long, lined with hairs and a waxy secretion, and closed at the bottom by a membrane, called *tympanum*, or "drum of the ear."

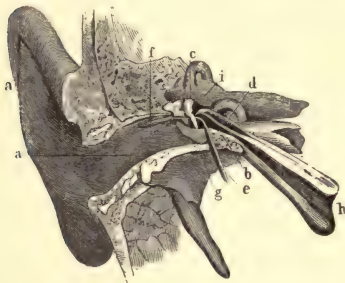


FIG. 349. — Section of Human Ear : *a*, external ear, with auditory canal ; *b*, tympanic cavity containing the three bones ; *c*, hammer, and its three muscles, *d*, *e*, *f* ; *g*, tympanic membrane, or head of the drum ; *h*, Eustachian tube leading to the pharynx ; *i*, labyrinth, with semi-circular canals and cochlea visible.

2. The middle ear, containing three little bones (the smallest in the body), *malleus*, *incus*, and *stapes*, articulated together. The cavity communicates with the external air by means of the Eustachian tube, which opens at the back part of the mouth.

3. The internal ear, or labyrinth, an irregular cavity in the solid part

of the temporal bone, and separated from the middle ear by a bony partition, which is perforated by two small holes. The labyrinth consists of the *vestibule*, or entrance ; the *semicircular canals* or tubes ; and the *cochlea*, or spiral canal. While the other parts are full of air, the labyrinth is filled with a liquid, and in this are the ends of the auditory nerve. The vibrations of the air, collected by the external ear, are concentrated upon the tympanum, and thence transmitted through the chain of little bones to the fluid in the labyrinth.

The essential organ of hearing is the labyrinth, which is, substantially, a bag filled with fluid and nerve filaments. Fishes generally have but little more. In amphibians and reptiles there are added a tympanum, a single bone, connecting this with the internal ear, the cochlea, and the Eustachian tube, the tympanum being

external. Birds have, besides, an auditory passage, opening on a level with the surface of the head, and surrounded by a circle of feathers. Most mammals have an external ear.

Sight is the perception of light.¹⁴⁷ In all animals it depends upon the peculiar sensitiveness of the optic organ to the luminous vibrations. In vertebrates the optic nerve comes from the middle mass of the brain, in invertebrates it is derived from a ganglion. Many animals are utterly destitute of visual organs, as the Protozoa, and the lower radiates and mollusks, besides intestinal worms and the blind fishes and many cave-animals; but the protozoan *Euglena* has a red pigment spot which is probably affected by light waves in a manner different from that in which the rest of the body is influenced. The eyes of the starfish are at the tips of its arms or rays. Those of the sea urchin form a ring at the dorsal pole of the body. Around the margin of the jellyfish are colored spots, supposed to be rudimentary eyes; but, as a lens is wanting, there is no image; so that the creature can merely distinguish light from darkness and color without form. Such an eye is nothing but a collection of pigment granules on the expansion of a nervous thread, and the perception of light is probably the sensation of warmth, the pigment absorbing the rays and converting them into heat.

Going higher, we find a lens introduced, forming a distinct image. The snail, for example, has two simple eyes, called *ocelli*, mounted on the tip of its long tentacles, each consisting of a globular lens,¹⁴⁸ with a transparent skin (cornea) in front, and a colored membrane (choroid) and a nervous network (retina) behind. The scallop (*Pecten*) has such eyes in



FIG. 350. — Eye of *Pecten*, much enlarged: *m*, mantle; *l*, lens; *r*, retina and choroid; *n*, nerve.

the edge of its mantle (Fig. 350). Such organs are the only eyes possessed by myriapods, spiders, scorpions,

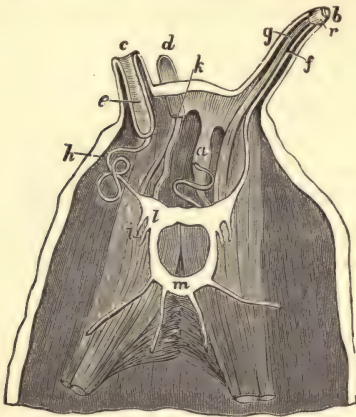


FIG. 351. — Head of a Snail bisected, showing structure of tentacles: *a*, right inferior tentacle retracted within the body; *b*, right superior tentacle fully protruded; *c*, left superior tentacle partially inverted; *d*, left inferior tentacle; *e*, optic nerve; *f*, retractor muscle; *g*, optic nerve in loose folds; *h*, retractor muscle of head; *i*, nerve and muscle of left inferior tentacle; *l, m*, nervous collar.

and caterpillars. Adult insects usually have three ocelli on the top of the head. But the proper visual organs of lobsters, crabs, and insects are two *compound eyes*, perched on pedestals, or fixed on the sides of the head. They consist of an immense number of ocelli pressed together so that they take an angular form — four-sided in Crustacea, six-sided in insects. They form two rounded protuberances variously colored — white, yellow, red, green,

purple, brown, or black. Under the microscope, the surface is seen to be divided into a host of facets,¹⁴⁹ each being an ocellus complete in itself. Each cornea is convex on one side, and either convex or flat on the other, so that it produces a focus like a lens. Behind the cornea, or lens, is the pigment, having a minute aperture or “pupil.” Next is a conical tube — one for each facet — with sides and bottom lined with pigment. These tubes converge to the optic ganglion, the fibers of which pass through the tubes to the cornea.¹⁵⁰ Vision by such a compound eye is not a mosaic;



FIG. 352. — Head of the Bee, showing compound eyes, the three ocelli, or stemmata, and the antennæ (magnified).

but each ocellus gives a complete image, although a different perspective from its neighbor. The multiplied images are reduced to one mental stereoscopic picture, on the principle of single vision in ourselves.

The eyes of the cuttlefish are the largest and the most perfect among invertebrates. They resemble the eyes of higher animals in

having a crystalline lens with a chamber in front (open, however, to the sea water), and a chamber behind it filled with "vitreous humor."

The eye of vertebrates is formed by the infolding of the skin to create a lens, and an outgrowth of the brain to make a sensitive layer; both inclosed in a white spherical case (*sclerotic*) made of tough tissue, with a transparent front, called the *cornea*.

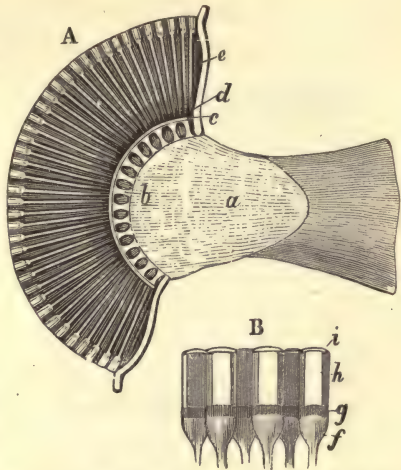


FIG. 353. — Eye of a Beetle (*Melolontha*): A, section; a, optic ganglion; b, secondary nerves; c, retina; d, pigment layer; e, proper optic nerves; B, group of ocelli (magnified); f, bulb of optic nerve; g, layer of pigment; h, vitreous humor; i, cornea.

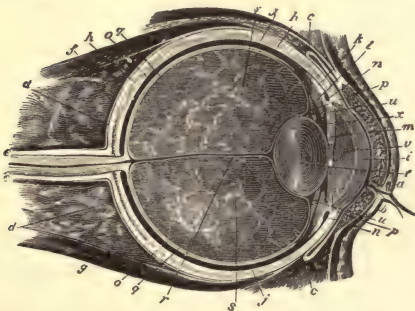


FIG. 354. — Section of Human Eye: a and b, upper and lower lid; c, conjunctiva, or mucous membrane, lining the inner surface; d, external membrane; e, sheath of optic nerve; f, g, muscles for rolling the eye up or down; h, sclerotic; i, transparent cornea; j, choroid; k, l, ciliary muscle for adjusting the eye for distance; m, iris and pupil; n, canal; o, retina; s, vitreous humor; t, crystalline lens; v, anterior chamber; x, posterior chamber.

This case is kept in shape by two fluids—the thin *aqueous humor* filling the cavity just behind the cornea,

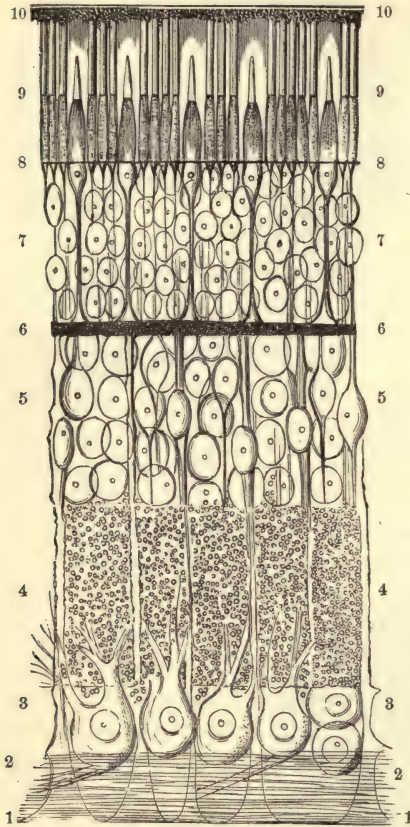


FIG. 355.—Section of the Human Retina, $\times 400$:
1, internal limiting membrane; 2, optic-nerve fibers;
3, ganglion cells; 4, internal molecular layer;
5, internal granules; 6, external molecular layer;
7, external granules; 8, external limiting membrane;
9, layer of rods and cones; 10, pigment layer.

and the jellylike *vitreous humor* occupying the larger posterior chamber. Between the two humors lies the double-convex *crystalline lens*. On the front face of the lens is a contractile circular curtain (*iris*), with a hole in the center (*pupil*); and lining the sclerotic coat is the *choroid* membrane, covered with dark pigment. The optic nerve, entering at the back of the eye through the sclerotic and choroid coats, expands into the transparent *retina*, which consists of several layers—fibrous, cellular, and granular. The most sensitive part is the surface lying next to the black pigment.

And here is a peculiarity of the vertebrate eye: the nerve fibers, entering from behind, turn back and look toward the bottom of the eye, so that vision is directed

backward ; while invertebrate vision is directly forward. In vertebrates only, the optic nerves cross each other (*decussate*) in passing from the brain to the eyes ; so that the right side of the brain, *e.g.*, receives the impressions of objects on the left side of the body.¹⁵¹

Generally, the eyes of vertebrates are on opposite sides of the head ; but in the flatfishes both are on the same side. Usually, both eyes see the same object at once ; but in most fishes the eyes are set so far back, the fields of vision are distinct. The cornea may be flat, and the lens globular, as in fishes ; or the cornea very convex, and the lens flattened, as in owls. Purely aquatic animals have neither eyelids nor tears, but nearly all others (especially birds) have three lids.¹⁵² The pupil is usually round ; but it may be rhomb-shaped, as in frogs ; vertically oval, as in crocodiles and cats ; or transversely oval, as in geese, doves, horses, and ruminants. Many quadrupeds, as the cat, have a membrane (*tapetum*) lining the bottom of the eyeball, with a brilliant metallic luster, usually green or pearly ; it is this which makes the eyes of such animals luminous in the dark.

2. *Instinct and Intelligence*

The simplest form of nervous excitement is mere sensation. Above this we have sensation awakening consciousness, out of which come those voluntary activities grouped together under the name of Instinct ; and, finally, Intelligence.

The lowest forms of life are completely mechanical, for their movements seem to be due solely to their organization. They are automatons, or creatures of necessity. In the higher animals certain actions are automatic, as breathing, the beating of the heart, the contractions of the iris, and all the first movements of

an infant.¹⁵³ But, generally, the actions of animals are not the result of mere bodily organization.

The inferior orders are under the control of **Instinct**, *i.e.*, an apparently untaught ability to perform actions which are useful to the animal.¹⁵⁴ They seem to be born with a measure of knowledge and skill (as man is said to have innate ideas), acquired neither by reason nor experiment. For what could have led bees to imagine that by feeding a worker larva with royal jelly, instead of beebread, it would turn out a queen instead of a neuter? In this case, neither the habit nor the experience could be inherited, for the worker bees are sterile. We can only guess that the discovery has been communicated by the survivors of an older swarm. Uniformity is another characteristic feature of instinct. Different individuals of the same species execute precisely the same movements under like circumstances. The career of one bee is the career of another. We do not find one clever and another stupid. Honeycombs are built now as they were before the Christian era. The creatures of pure instinct appear to be tied down, by the constitution of their nervous system, to one line of action, from which they can not spontaneously depart. The actions vary only as the structure changes.¹⁵⁵ There is a wonderful fitness in what they do, but there is no intentional adaptation of means to ends.

All animals, from the starfish to man, are guided more or less by instinct; but the best examples are furnished by the insect world, especially by the social hymenoptera (ants, bees, and wasps). The butterfly carefully provides for its young, which it is destined never to see; many insects feed on particular species of plants, which they select with wonderful sagacity; and monkeys avoid poisonous berries; bees and squirrels store up food for the future; bees, wasps, and spiders construct

with marvelous precision ; and the subterranean chambers of ants and the dikes of the beaver show engineering skill ; while salmon go from the ocean up the rivers to spawn ; and birds of the temperate zones migrate with great regularity.

But in the midst of this automatism there are the glimmerings of intelligence and free will. We see some evidence of choice and of designed adaptation. Pure instinct should be infallible. Yet we notice mistakes that remind us of mental aberrations. Bees are not so economical as has been generally supposed. A mathematician can make five cells with less wax than the bee uses for four ; while the humblebee uses three times as much material as the hive bee. An exact hexagonal cell does not exist in nature. Flies lay eggs on the carrion plant because it happens to have the odor of putrid meat. The domesticated beaver will build a dam across its apartment. Birds frequently make mistakes in the construction and location of their nests. In fact, the process of cheating animals relies on the imperfection of instinct. Nor are the actions of the brute creation always perfectly uniform ; and, so far as animals conform to circumstances, they act from intelligence, not instinct. There is proof that some animals profit by experience. Birds do learn to make their nests ; and the older ones build the best. Trappers know well that young animals are more easily caught than old ones. Birds brought up from the egg, in cages, do not make the characteristic nests of their species ; nor do they have the same song peculiar to their species, if they have not heard it. Chimney swallows certainly built their nests differently in America three hundred years ago. A bee *can* make cells of another shape, for it sometimes does ; its actions, therefore, being elective and conditional, are in a measure the result of calculation.

The mistakes and variations of instinct are indications that animals have something more — a limited range of that principle of **Intelligence** so luminous in man. No precise line can be drawn between instinctive and intelligent acts; all we can say is, there is more freedom of choice in the latter than the former; and that some animals are most instinctive, others most intelligent. Thus, we speak of the instinct of the ant, bee, and beaver, and the intelligence of the elephant, dog, and monkey. Instinct loses its peculiar character as intelligence becomes developed. Ascending from the worm and oyster to the bee, we see the movements become more complex in character and more special in their objects; but instinct is supreme. Still ascending, we observe a gradual fading away of the instincts, till they become subordinate to higher faculties—will and reason. We can predict with considerable certainty the actions of animals guided by pure instinct; but in proportion as they possess the power of adapting means to ends, the more variable their actions. Thus, the architecture of birds is not so uniform as that of insects.¹⁵⁶

We must credit brutes with a certain amount of observation and imitation, curiosity and cunning, memory and reason. Animals have been seen to pause, deliberate, or experiment and resolve. The elephant and horse, dog and monkey, particularly, participate in the rational nature of man, up to a certain point. Thinking begins wherever there is an intentional adaptation of means to ends; for that involves the comparison and combination of ideas. Animals interchange ideas: the whine of a dog at the door on a cold night certainly implies that he wants to be let in. Bees and ants, it is well known, confer by touching together their antennæ. All the higher animals, too, have similar emotions — as joy, fear, love, and anger.

While instinct culminates in insects, the highest development of intelligence is presented in man.¹⁵⁷ In man only does instinct cease to be the controlling power. He stands alone in having the whole of his organization conformed to the demands of his brain; and his intelligent acts are characterized by the capacity for unlimited progress. The brutes can be improved by domestication; but, left to themselves, they soon relapse into their original wildness. Civilized man also goes back to savagery; yet man (though not all men) has the ambition to exalt his mental and moral nature. He has a soul, or conscious relation to the infinite, which leads him to aspire after a lofty ideal. Only he can form abstract ideas. And, finally, he is a completely self-determining agent, with a prominent will and conscience — the highest attribute of the animal creation. In all this, man differs profoundly from the lower forms of life.

3. *The Voices of Animals*

Most aquatic animals are mute. Some crabs make noises by rubbing their fore legs against their carapace; and many fishes produce noises in various ways, mostly by means of the swim bladder. Insects are the invertebrates which make the most noise. Their organs are usually external, while those of vertebrates are internal. Insects of rapid flight generally make the most noise. In some the noise is produced by friction (stridulation); in others, by the passage of air through the spiracles (humming). The shrill notes of crickets and grasshoppers are produced by rubbing the wings against each other, or against the thighs; but the cicada, or harvest fly, has a special apparatus — a tense membrane on the abdomen, acted upon by muscles. The buzzing of flies and humming of bees are caused, in part, by the vibra-

tions of the wings; but the true voice of these insects comes from the spiracles of the thorax.

Snakes and lizards have no vocal cords, and can only hiss. Frogs croak ¹⁵⁸ and crocodiles roar, and the huge tortoise of the Galapagos Islands utters a hoarse, bellowing noise.

The vocal apparatus in birds is situated at the lower end of the trachea, where it divides into the two bronchi.¹⁵⁹ It consists mainly of a bony drum, with a cross bone, having a vertical membrane attached to its upper edge. The membrane is put in motion by currents of air passing on either side of it. Five pairs of muscles (in the songsters) adjust the length of the windpipe to the pitch of the glottis. The various notes are produced by differences in the blast of air, as well as by changes in the tension of the membrane. The range of notes is commonly within an octave. Birds of the same family have a similar voice. All the parrots have a harsh utterance; geese and ducks quack; crows, magpies, and jays caw; while the warblers differ in the quality, rather than the kind, of note.¹⁶⁰ The parrot and mocking bird use the tongue in imitating human sounds. Some species possess great compass of voice. The bell-bird can be heard nearly three miles; and Livingstone said he could distinguish the voices of the ostrich and the lion only by knowing that the former roars by day, and the latter by night.

The vocal organ of mammals, unlike that of birds, is in the upper part of the larynx. It consists of four cartilages, of which the largest (the *thyroid*) produces the prominence in the human throat known as "Adam's apple," and two elastic bands, called "vocal cords," just below the glottis, or upper opening of the windpipe. The various tones are determined by the tension of these cords, which is effected by the raising or lower-

ing of the thyroid cartilage, to which one end of the cords is attached. The will cannot influence the contraction of the vocalizing muscles, except in the very act of vocalization. The vocal sounds produced by mammals may be distinguished into the ordinary voice, the cry, and the song. The second is the sound made by brutes. The whale, porpoise, armadillo, ant-eater, porcupine, and giraffe are generally silent. The bat's voice is probably the shrillest sound audible to human ears. There is little modulation in brute utterance. The opossum purrs, the sloth and kangaroo moan, the hog grunts or squeals, the tapir whistles, the stag bellows, and the elephant gives a hoarse trumpet sound from its trunk and a deep groan from its throat. All sheep have a guttural voice; all the ox family low, from the bison to the musk ox; all the horses and donkeys neigh; all the cats *miaü*, from the domestic animal to the lion; all the bears growl; and all the canine family — fox, wolf, and dog — bark and howl. The howling monkeys and gorillas have a large cavity, or sac, in the throat for resonance, enabling them to utter a powerful voice; and one of the gibbon apes has the remarkable power of emitting a complete octave of musical notes. The human voice, taking the male and female together, has a range of nearly four octaves. Man's power of speech, or the utterance of articulate sounds, is due to his intellectual development rather than to any structural difference between him and the apes. Song is produced by the vocal cords, speech by the mouth.



FIG. 356. — Human Larynx, seen in profile; *a*, half of the hyoid bone; *e*, trachea; *f*, esophagus; *g*, epiglottis.

CHAPTER XXII

REPRODUCTION

It is a fundamental truth that every living organism has had its origin in some preëxisting organism. The doctrine of "spontaneous generation," or the supposed origination of organized structures out of inorganic particles, or out of dead organic matter, has not yet been sustained by facts.

Reproduction is of two kinds — *sexual* and *asexual*. All animals, probably, have the first method, while a very great number of the lower forms of life have the latter also.

Of asexual reproduction there are two kinds — *Self-division* (*Fission*) and *Budding*.

Self-division, the simplest mode possible, is a natural breaking-up of the body into distinct surviving parts. This process is sometimes extraordinarily rapid, the increase of one animalcule (*Paramecium*) being computed at 268 millions in a month. It may be either *transverse* or *longitudinal*. Of the first sort, Fig. 10 is an example; of the latter, Fig. 11, *a*. This form of reproduction is, naturally, confined to animals whose tissues and organs are simple, and so can easily bear division, or whose parts are so arranged as to be easily separable without serious injury. The process is most common in Protozoa, worms, and polyps.

Budding is separated by no sharp line from self-division. While in the latter a part of the organs of the parent go to the offspring, in the former one or

more cells of the original animal begin to develop and multiply so as to grow into a new animal like the parent. The process in animals is quite akin to the same operation in plants. The buds may remain permanently attached to the parent stock, thus making a colony, as in corals and Bryozoa (*continuous budding*), or they may be detached at some stage of growth (*discontinuous budding*). This separation may occur when the bud is grown up, as in hydra (Fig. 18), or as in plant lice, daphnias (Fig. 56), and among other animals the buds may be internal, becoming detached when entirely undeveloped and externally resembling an egg. They differ, however, entirely from a true egg in developing directly, without fertilization.

Sexual Reproduction requires cells of two kinds, usually from different animals. These are the germ cell or egg, and the sperm cell. The embryo is developed from the cells which are formed by the repeated divisions of the ovum which take place as a result of its union with the sperm cell.¹⁶¹

The egg consists essentially of three parts, the *germinal vesicle*, the *yolk*, and the *vitelline membrane*, which surrounds both the first. It is ordinarily globular in shape. Of the three parts, the primary one is the germinal vesicle — a particle of protoplasm. The yolk serves as food for this, and the membrane protects both. When a great mass of yolk is present it is divisible into two parts — *formative* and *food yolk*. The latter is of a more oily nature than the former, and is usually not segmented with the egg. The structure of the hen's egg is more complicated. The outside shell consists of earthy matter (lime) deposited in a network of animal matter. It is minutely porous, to allow the passage to and from of vapor and air. Lining the shell is a double membrane (*membrana putaminis*) resembling delicate

tissue paper. At the larger end it separates to inclose a bubble of air for the use of the chick. Next comes



FIG. 357. — Diagram of a cell: *w*, cell wall, with inclosed cytoplasm; *n*, nucleus, consisting of nuclear membrane inclosing granular substance in which are seen a spherical *nucleolus* and several irregular masses of *chromatin*; *a*, attraction sphere containing a centrosome.

the albumen, or "white," in spirally arranged layers, within which floats the yolk. The yolk is prevented from moving toward either end of the egg by two twisted cords of albumen, called *chalazæ*; yet is allowed to rise toward one side, the yolk being lighter than the albumen. The yolk is composed of oily granules (about $\frac{1}{250}$ of an inch in diameter), and is inclosed in a sac, called the *vitelline membrane*, and disposed in concentric layers, like a set of vases placed one within the other. That part

of the yolk which extends from the center to a white spot (*cicatricula*) on the outside can not be hardened, even with the most prolonged boiling. The *cicatricula*, or embryo spot, is a thin disk of cellular structure, in which the new life first appears. This was originally a simple cell, but development has gone some

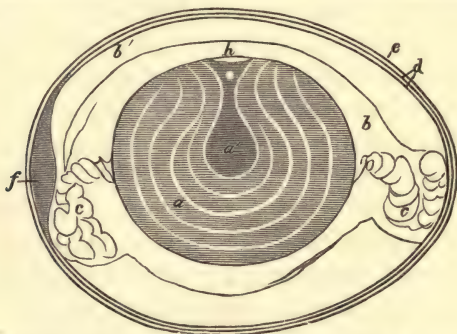


FIG. 358. — Longitudinal section of Hen's Egg before incubation: *a*, yolk, showing concentric layers; *a'*, its semifluid center, consisting of a white granular substance — the whole yolk is inclosed in the vitelline membrane; *b*, inner dense part of the albumen; *b'*, outer, thinner part; *c*, the chalaza, or albumen, twisted by the revolutions of the yolk; *d*, double shell membrane, split at the large end to form the chamber, *f*; *e*, the shell; *h*, the white spot, or cicatricula.

way before the egg is laid. It is always on that side which naturally turns uppermost, for the yolk can turn upon its axis; it is, therefore, always nearest to the external air and to the hen's body — two conditions necessary for its development. There is another reason for this polarity of the egg: the lighter and more delicate part of the yolk is collected in its upper region, while the heavy, oily portion remains beneath.

In most eggs the shell and albumen are wanting. When the albumen is present, it is commonly covered by a membrane only. In sharks the envelope is horny; and in crocodiles is calcareous, as in birds.

The egg of the sponge has no true vitelline membrane, and is not unlike an ordinary amœboid cell. An egg is, in fact, little more than a very large cell, of which the germinal vesicle is the nucleus.



FIG. 359. — Egg of Sponge (magnified): *n*, nucleus.

The size of an egg depends mainly upon the quantity of yolk it contains; and to this is proportioned the grade of development which the embryo attains when it leaves the egg.¹⁶² In the eggs of the starfishes, worms, insects, mollusks (except the cuttlefishes), many amphibians, and mammals, the yolk is very minute and formative, *i.e.*, it is converted into the parts of the future embryo. In the eggs of lobsters, crabs, spiders, cephalopods, fishes, reptiles, and birds, the yolk is large and colored, and consists of two parts — the formative, or germ yolk, immediately surrounding the germinal vesicle; and the nutritive, or food yolk, constituting the greater part of the mass, by which the young animal in its egg life is nourished. In the latter case, the young come forth more mature than when the food yolk is wanting.

As to form, eggs are oval or elliptical, as in birds and crocodiles; spherical, as in turtles and wasps; cylindrical, as in bees and flies; or shaped like a handbarrow, with tendrils on the corners, as in the shark. The eggs of some very low forms are sculptured or covered with hairs or prickles.

The number of eggs varies greatly in different animals, as it is in proportion to the risks during development. Thus, the eggs of aquatic tribes, being unprotected by the parent, and being largely consumed by many

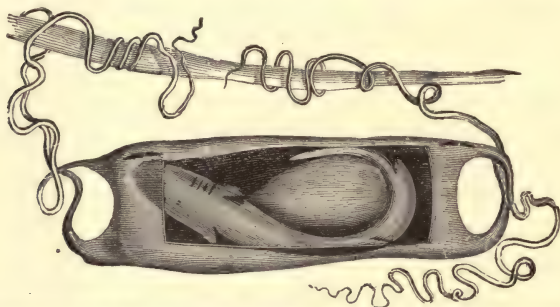


FIG. 360. — Egg of a Shark (the external gills of the embryo are not represented).

animals, are numerous to prevent extinction. The spawn of a single cod contains millions of eggs; that of the oyster, 6,000,000. A queen bee, during the five years of her existence, lays about a million eggs.

Eggs are laid one by one, as by birds; or in clusters, as by frogs, fishes, and most invertebrates. The spawn of the sea snails consists of vast numbers of eggs adhering together in masses, or in sacs, forming long strings.

As a rule, the higher the rank, the more care animals take of their eggs and their young, and the higher the temperature needed for egg development. In the majority of cases, eggs are left to themselves. The freshwater mussel (*Unio*) carries them within its gills, and

the lobster under its tail. The eggs of many spiders are enveloped in a silken cocoon, which the mother guards with jealous care. Insects, as flies and moths, deposit their eggs where the larva, as soon as born, can procure its own food. Most fishes allow their spawn, or roe, to float in the water; but a few build a kind of flat nest in the sand or mud, hovering over the eggs until they are hatched; while the Acará of the Amazon carries them in its mouth. The amphibians, generally, envelop their eggs in a gelatinous mass, which they leave to the elements; but the female of the Surinam toad carries hers on her back, where they are placed by the male. The great Amazon turtles lay their eggs in holes two feet deep, in the sand; while the alligators simply cover theirs with a few leaves and sticks. Nearly all birds build nests, those of the perchers being most elaborate, as their chicks are dependent for a time on the parent.¹⁶³ The young of marsupials, as the kangaroo, which are born in an extremely immature state, are nourished in a pouch outside of the body. But the embryo of all other mammals is developed within the parent to a more perfect condition, by means of a special organ, the *placenta*. It is a general law, that animals receiving in the embryo states the longest and most constant parental care ultimately attain the highest grade of development.

The Protozoa, which have no true eggs, have a sort of reproduction called *conjugation*. In this process two individuals unite into one mass, surround themselves with a case, in which they divide into several parts, each portion becoming a new individual, or the process may be followed by repeated divisions of the two individuals which separate as soon as the process is finished, as in *Paramecium*, or remain fused together, as in *Vorticella*.

The sperm cells differ from the egg in being very small, commonly motile, and in that a large number are usually produced from a single primary reproductive cell, while the egg represents the entire primary cell. The union of the sperm cell with the germinal vesicle (*fertilization*) is the first step in development, and without it the egg will not develop normally.

CHAPTER XXIII*

DEVELOPMENT

Development is the evolution of a germ into a complete organism. The study of the changes in the developing embryo constitutes the science of Embryology; the transformations after the egg life are called metamorphoses, and include growth and repair.

The process of development is a passage from the general to the special, from the simple to the complex, from the homogeneous to the heterogeneous, by a series of differentiations. It brings out first the profounder distinctions, and afterward those more external. That is, the most essential parts appear first. And not only does development tend to make the several organs of an individual more distinct from one another, but also the individual itself more distinguished from other individuals and from the medium in which it lives. With advancing development, the animal, as a rule, acquires a more specific, definite form, and increases in weight and locomotive power. Life is a tendency to individuality.

The first step in development, after fertilization, is the segmentation of the egg, by a process of self-division. In the simplest form, the whole yolk divides into two parts; these again divide repeatedly, making four, eight, sixteen, etc., parts, until the whole yolk is subdivided

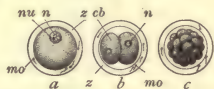


FIG. 361. — Fertilization and segmentation of mammalian ovum: *mo*, spermatozoön; *n*, nucleus; *nu*, nucleolus; *z*, zona radiata; *cb*, segmenting cell.

* See Appendix.

into very small portions (cells) surrounding a central cavity. This stage is known as the "mulberry mass," or *blastula* (Fig. 361, *c*). If the yolk is larger, relatively to the germinal vesicle, the process of division may go on more slowly in one of the two parts of the egg, first formed; or in very large eggs, like those of birds and cuttlefishes, only a small part of the yolk subdivides.

In some form, the process of segmentation is found in the eggs of all animals, as is also the following stage. This step is the differentiation of the single layer of cells into two parts, one for the body wall, the other for

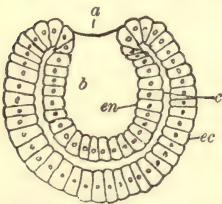


FIG. 362. — Diagram of Gastrula of a Worm (*Sagitta*): *a*, primitive mouth; *b*, primitive digestive cavity; *c*, primitive body cavity; *en*, endoderm; *ec*, ectoderm.

the wall of the digestive tract. In the typical examples, this is accomplished by one part of the wall of the blastula turning in so far as to convert the blastula into a sort of double-walled cup, the *gastrula* (Fig. 362). One half of the wall of the blastula is now the outer wall of the germ, the other half that of the digestive cavity; the original blastula cavity is now

the body cavity, the new cavity formed by the infolding is the stomach and its opening is both mouth and vent (Fig. 362). Some adult animals are little more than such a sac. *Hydra* (Fig. 18), for instance, is little different from a gastrula with tentacles, and one of its relatives wants even these additions.

Ordinarily, however, development goes much further. From the two original layers arises, in various ways, a third between them, making the three primitive germ layers—*epiblast*, *mesoblast*, and *hypoblast*. This new layer is necessarily in the primitive body cavity, which it may fill up; or usually a new body cavity is formed, in different ways in different groups. In by far the

great majority of animals the digestive tract gets a new opening, which usually becomes the mouth; and the old mouth may close, or serve only the functions of the vent. From this point the development of each group must be traced in detail.

Development of a Hen's Egg. — After the segmentation, the germinal disk divides into two layers, between which a third is soon formed. The upper layer (*epiblast*) gives rise to the epidermis, brain, spinal cord, retina, crystalline lens, and internal ear. From the lower layer (*hypoblast*) is formed the epithelium of the digestive canal. From the middle layer (*mesoblast*) come all the other organs — muscles, bones, blood vessels, etc. The mesoblast

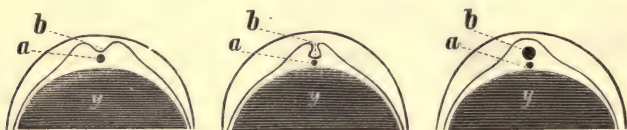


FIG. 363. — Transverse vertical sections of an egg, showing progressive stages of development: *a*, notochord; *b*, medullary furrow, becoming a closed canal in the last.

thickens so as to form two parallel ridges running lengthwise of the germ, and leaving a groove between them (*medullary furrow* and *ridges*).¹⁶⁴ The ridges gradually rise, carrying with them the epiblast, incline toward each other, and at last unite along the back. So that we have a tube of epiblast surrounded by mesoblast, which is itself covered by epiblast. This tube becomes the brain and spinal cord, whose central canal, enlarging into the ventricles of the brain, tells the story of its original formation. Beneath the furrow, a delicate cartilaginous thread appears (called *notochord*) — the predecessor of the backbone. Meanwhile the mesoblast has divided into two layers, except in the middle of the animal, beneath the spinal cord, and in the head. One of these layers remains attached to the epiblast, and

with it forms the body wall; the other bends rapidly downward, carrying the hypoblast with it, and forms the wall of the intestine. The space thus left between the layers of the mesoblast is the body cavity. At the same time, the margin of the germ extends farther and farther over the yolk, till it completely incloses it. So that now we see two cavities — a small one, containing the nervous system; and a larger one below, for the digestive organs. Presently, numerous rows of corpuscles are seen on the middle layer, which are subsequently inclosed, forming a network of capillaries, called the vascular area. A dark spot indicates the situation of the heart, which is the first distinctly bounded cavity



FIG. 364. — Rudimentary Hearts, human : 1, venous trunks; 2, auricle; 3, ventricle; 4, bulbus arteriosus.

of the circulatory system. It is a short tube lying lengthwise just behind the head, with a feeble pulsation,

causing the blood to flow backward and forward. The tube is gradually bent together, until it forms a double cavity, resembling the heart of a fish. On the fourth day of incubation partitions begin to grow, dividing the cavities into the right and left auricles and ventricles. The septum between the auricles is the last to be finished, being closed the moment respiration begins. The blood vessels ramify in all directions over the yolk, absorbing its substance, and all performing the same office; it is not till the fourth or fifth day that arteries can be distinguished from veins, by being thicker, and by carrying blood only from the heart.¹⁶⁵

The embryo lies with its face, or ventral surface, toward the yolk, the head and tail curving toward each other. Around the embryo on all sides the epiblast and upper layer of the mesoblast rise like a hood

over the back of the embryo till they form a closed sac, called the *amnion*. It is filled with a thin liquid, which serves to protect the embryo. Meanwhile, another important organ is forming on the other side. From the

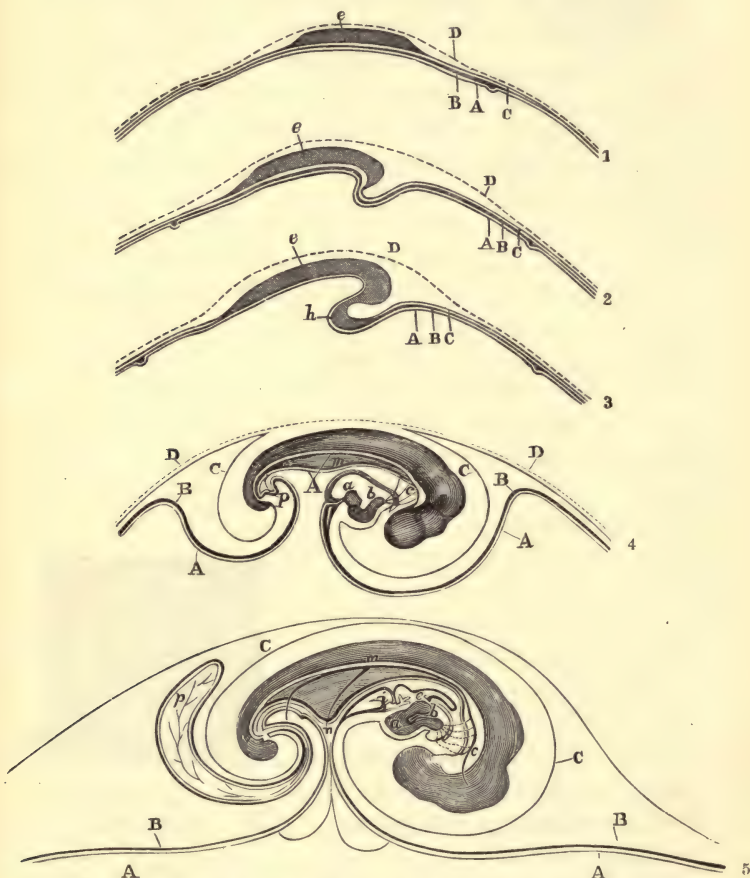


FIG. 365.—Embryo in a Hen's Egg during the first five days, longitudinal view : A, hypoblast ; B, lower layer of mesoblast ; C, upper layer of mesoblast and epiblast united, in the last figures forming the amniotic sac ; D, vitelline membrane ; *e*, thickened blastoderm, the first rudiment of the dorsal part (in the last figure it marks the place of the lungs) ; *h*, heart ; *a*, *b*, its two chambers ; *c*, aortic arches ; *m*, aorta ; *i*, liver ; *p*, allantois.

hinder portion of the alimentary canal an outgrowth is formed which extends beyond the wall of the embryo



FIG. 366. — The hen's egg at the end of the ninth day of incubation, seen in vertical section. The embryo naturally lies with its left side on the yolk sac, but has been lifted up in order to show its shape more clearly: *an*, inner or true amnion; *hm*, hyomandibular cleft; *sv*, air chamber; *ta*, allantois; *wa*, white or albumen; *ys*, yolk sac.

proper into the cavity of the amnion, and spreads out over the whole inner surface of the shell, so that it partly surrounds both embryo and inner layer of the amnion (*amnion proper*). This is the *allantois*. It is full of blood vessels, and it serves as the respiratory organ until the chick picks the shell and breathes by its lungs.¹⁶⁶ The *chorion* is the outermost part of the allantois, and the *placenta* of mammals is the shaggy, vascular edge of the chorion.

The alimentary canal is at first a straight tube closed at both ends, the middle being connected with the yolk sac. As it grows faster than the body, it is thrown into a spiral coil; and at several points it dilates, to form the crop, stomach, gizzard, etc. The mouth is developed from an infolding of the skin. The liver is an outgrowth from the digestive tube, at first a cluster of cells, then of follicles, and finally a true gland. The lungs are developed on the third day as a minute bud from the upper part of the alimentary canal, or pharynx. As they grow in size, they pass from a smooth to a cellular condition.

The skeleton at the beginning consists, like the notochord, of a cellular material, which gradually turns to cartilage. Then minute canals containing blood vessels arise, and



FIG. 367. — View of embryo with its foetal membrane: *am*, amnion proper; *d*, dwindled yolk sac; *al*, allantois; *al'*, subzonal membrane; *z*, villi; outside the subzonal membrane there is the delicate ectodermic trophoblast, *z'*.

earthy matter (chiefly phosphate of lime) is deposited between the cells. The primary bone thus formed is compact: true osseous tissue, with canaliculi, laminae, and Haversian canals, is the result of subsequent absorption.¹⁶⁷ Certain bones, as those of the face and cranium, are not preceded by cartilage, but by connective tissue; these are called *membrane bones*. Ossification, or bone making, begins at numerous distinct points, called *centers of ossification*; and, theoretically, every center stands for a bone, so that there are as many bones in a skeleton as centers of ossification. But the actual number in the adult animal is much smaller, as many of the centers coalesce.¹⁶⁸ The development of the backbone is not from the head or from the tail, but from a central point midway between; there the first vertebræ appear, and from there they multiply forward and backward.

The limbs appear as buds on the sides of the body; these lengthen and expand so as to resemble paddles — the wings and legs looking precisely alike; and, finally, they are divided each into three segments, the last one subdividing into digits. The feathers are developed from the outside cells of the epidermis: first, a horny cone is formed, which elongates and spreads out into a vane, and this splits up into barbs and barbules.

The muscle fibers are formed either by the growth in length of a single cell, or by the coalescence of a row of cells; the cell wall thus produces a long tube — the sarcolemma of a fiber — and the granular contents arrange themselves into linear series, to make fibrillæ.

Nervous tissue is derived from the multiplication and union of embryo cells. The white fibers at first resemble the gray. The brain and spinal marrow are developed from the epiblastic lining of the medullary furrow. Soon the brain, by two constrictions, divides into fore

brain, mid brain, and hind brain. The fore brain throws out two lateral hemispheres (cerebrum), and from these protrude forward the two olfactory lobes. From the mid brain grow the optic lobes; and the hind brain is separated into cerebellum and medulla oblongata. The essential parts of the eye, retina and crystalline lens, are developed, the former as a cuplike outgrowth from the fore brain, the latter as an ingrowth of the epidermis. An infolding of the epidermis gives rise to the essential parts of the inner ear, and from the same layer come the olfactory rods of the nose and the taste buds of the tongue. So that the central nervous system and the essential parts of most of the sense organs have a common origin.

Modes of Development. — The structure and embryology of a hen's egg exhibit many facts which are common to all animals. But every grand division of the animal kingdom has its characteristic method of developing.

Protozoans differ from all higher forms in having no true eggs.

The egg of the hydroid, after segmentation, becomes a hollow, pear-shaped body, covered with cilia. Soon one end is indented; then the indentation deepens until it reaches the interior and forms the mouth. The animal fastens itself by the other end, and the tentacles appear as buds. In the sea anemone, the stomach is turned in, and the partitions appear in pairs.

In the oyster, the egg segments into two unequal parts, one of which gives rise to the digestive tract and its derivatives, while from the smaller part originate the skin, gills, and shell. It is soon covered with cilia, by whose help it swims about.

The embryo of an insect shows from the first a right and left side; but the first indication that it is an articulate is the development of a series of indentations divid-

ing the body into successive rings, or joints. Next, we observe that the back lies near the center of the egg, the ventral side looking outward, *i.e.*, the embryo is doubled upon itself backward. And, finally, the appearance of three pairs of legs proves that it will be an insect, rather than a worm, crustacean, or spider.

The vertebrate embryo lies with its stomach toward the yolk, reversing the position of the articulate; but the grand characteristic is the medullary groove, which does not exist in the egg of any invertebrate. This feature is connected with another, the setting apart of two distinct regions — the nervous and nutritive. There are three modifications of vertebrate development: that of fishes and amphibians, that of true reptiles and birds, and that of mammals. The amnion and allantois are wanting in the first group; while the placenta (which is the allantois vitally connected with the parent) is peculiar to mammals. In mammals, the whole yolk is segmented; in birds, segmentation is confined to the small white speck (*blastoderm*) seen in opening the shell.

At the outset, all animals, from the sponge to man, are structurally alike. All, moreover, undergo segmentation, and most have one form or other of the gastrula stage. But while vertebrates and invertebrates can travel together on the same road up to this point, here they diverge — never to meet again. For every grand group early shows that it has a peculiar type of construction. Every egg is from the first impressed with the power of developing in one direction only, and never does it lose its fundamental characters. The germ of the bee is divided into segments, showing that it belongs to the articulates; the germ of the lion has the medullary furrow — the mark of the coming vertebrate. The blastodermic layer of the vertebrate egg rolls up into two tubes — one to hold the viscera, the other to con-

tain the nervous cord: while that of the invertebrate egg forms only one such tubular division. The features which determine the branch to which an animal belongs are first developed, then the characters revealing its class.

There are differences also in grade of development as well as type. For a time there is no essential difference between a fish and a mammal; they have similar nervous, circulatory, and digestive systems. There are many such cases, in which the embryo of an animal represents the permanent adult condition of some lower form. In other words, the higher species, in the course of their development, offer likenesses, or analogies, to finished lower species. The human germ at first resembles that of all other metazoa in that it is a single cell. In the course of its development, the appearance of a medullary furrow excludes it at once from all invertebrates. It afterward has, for a time, structures found as permanent organs in the lower classes and orders of vertebrates. For a time, indeed, the human embryo so closely resembles that of the lower forms as to be indistinguishable from them; but certain structures belonging to those forms are kept long after the embryo is clearly human. For instance, the embryos of birds and mammals at an early stage have gill slits, like fishes. Not all the members of a group reach the same degree of perfection, some remaining in what corresponds to the immature stages of the higher animals. Such may be called permanently embryonic forms.

Sometimes an embryo develops an organ in a rudimentary condition, which is lost or useless in the adult. Thus, the Greenland whale, when grown up, has not a tooth in its head, while in the embryo life it has teeth in both jaws; unborn calves have canines and upper incisors; and the female dugong has tusks which never

cut the gum. The "splint bones" in the horse's foot are undeveloped metatarsals.

Animals differ widely in the degree of development reached at ovulation and at birth. The eggs of frogs are laid when they can hardly be said to have become fully formed as eggs, since they undergo still further change in the water. The eggs of birds are laid when segmentation is far advanced, while the eggs of mammals are retained by the parent till after the egg stage is passed.¹⁶⁹ Ruminants and terrestrial birds are born with the power of sight and locomotion. Most carnivores, rodents, and perching birds come into the world blind and helpless; while the human infant is dependent for a much longer time.

1. *Metamorphosis*

Few animals come forth from the egg in perfect condition. The vast majority pass through a great variety of forms before reaching maturity. These metamorphoses (which are merely periods of growth) are not peculiar to insects, though more apparent in them. Man himself is developed on the same general principles as the butterfly, but the transformations take place gradually. The coral, when hatched, has six pairs of partitions; afterward, the spaces are divided by six more pairs; then twelve intermediate pairs are introduced; next, twenty-four, and so on. The embryonic starfish has a long body, with six arms on a side, in one end of which the young starfish is developed. Soon the twelve-armed body is absorbed, and the young animal is perfectly formed. Worms are continually growing by the addition of new segments. Nearly all insects undergo complete metamorphosis. *i.e.*, exhibit four distinct stages of existence — egg, larva, pupa, and imago.

The wormlike larva¹⁷⁰ may be called a locomotive egg. It has little resemblance to the parent in structure or

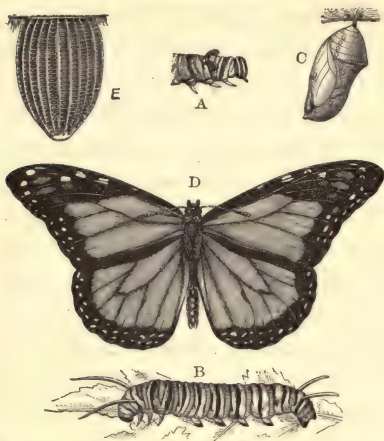


FIG. 368.—Milkweed butterfly: A, head of young larva; B, larva; C, pupa; D, imago; E, egg (magnified).

habits, eating and growing rapidly. Then it enters the pupa state, wrapping itself in a cocoon, or case, and remaining apparently dead till new organs are developed, when it escapes a perfect winged insect, or imago.¹⁷¹ Wings never exist externally in the larva; and some insects which undergo no apparent metamorphosis, as lice, are wingless. The

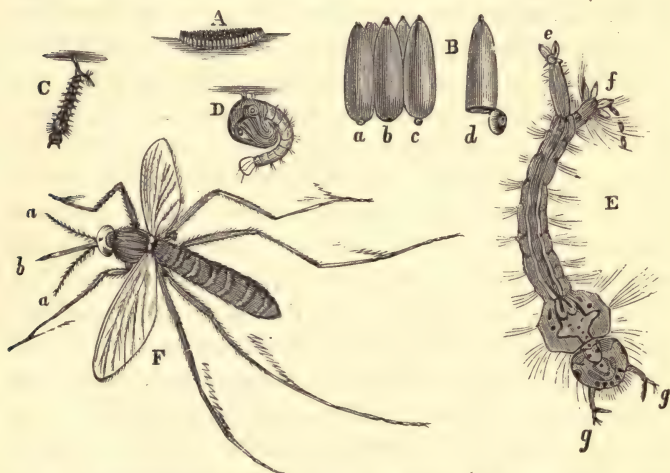


FIG. 369.—Metamorphosis of the Mosquito (*Culex pipiens*): A, boat of eggs; B, some of the eggs highly magnified; C, with lid open for the escape of the larva; D, pupa; E, larva magnified, showing respiratory tube, *e*, anal fins, *f*, antennæ, *g*; F, imago; *a*, antennæ; *b*, beak.

grasshopper develops from the young larva to the winged adult without changing its mode of life. In the development of the common crab, so different is the outward form of the newly hatched embryo from that of the adult, that the former has been described as a distinct species.

The most remarkable example of metamorphosis among vertebrates is furnished by the amphibians. A

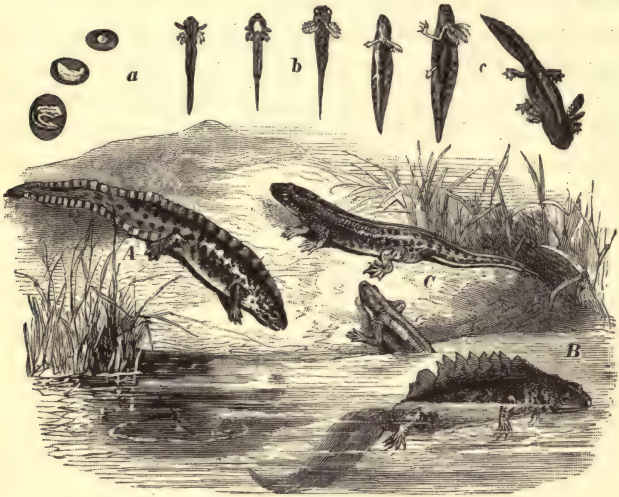


FIG. 370. — Metamorphosis of the Newt.

tadpole — the larva of a frog — has a tail, but no legs ; gills, instead of lungs ; a heart precisely like that of the fish ; a horny beak for eating vegetable food, and a spiral intestine to digest it. As it matures, the hinder legs show themselves, then the front pair ; the beak falls off ; the tail and gills waste away ; lungs are formed ; the digestive apparatus is changed to suit an animal diet ; the heart is altered to the reptilian type by the addition of another auricle ; in fact, skin, muscles, nerves, bones, and blood vessels vanish, being ab-

sorbed atom by atom, and a new set is substituted. *Molting*, or the periodical renewal of epidermal parts, as the shell of the lobster, the skin of the toad, the scales of snakes, the feathers of birds, and the hair of mammals, may be termed a metamorphosis. The change from milk teeth to a permanent set is another example.

An animal rises in organization as development advances. Thus, a caterpillar's life has nothing nobler about it than the ability to eat, while the butterfly expends the power garnered up by the larva in a gay and busy life. But there are seeming reversals of this law. Some mature animals appear lower in the scale than their young. The larval cirripede has a pair of magnificent compound eyes and complex antennæ; when adult, the antennæ are gone, and the eyes are reduced to a single, simple, minute eye spot. The germs of the sedentary sponge and oyster are free and active. The adult animal, however, is superior in alone possessing the power of reproduction. Such a change from an active to a fixed condition is known as *retrograde metamorphosis*.

There are certain larval forms so characteristic of the great groups of the animal kingdom as to demand notice. Most worms leave the egg as a larva, called



FIG. 371. — Trochosphere of Worm, magnified: *m*, mouth; *a*, anus; *c*, circle of cilia.

the *trochosphere* (Fig. 371), an oval larva, having mouth and anus, and a circle of cilia anterior to the mouth. This larval stage is common to worms with the most diverse adult forms and habits. It



FIG. 372. — Veliger of Snail, magnified: *v*, velum; *f*, foot; *s*, shell.

is also found in many of the mollusks. The mollusks usually pass through a later stage called the *veliger* (Fig. 372), in which a circle of cilia homologous to that of the trochosphere is borne by a lobed expansion

on the head, called the *velum*, or sail. The Crustacea, which exhibit so great a range of form in the adult state, all pass through a stage in which they are substantially alike. Forms as different in appearance as barnacles, entomostracans, and prawns hatch out as *Nauplii*, little oval animals, with a straight intestine, three pairs of legs, and a simple eye (Fig. 373). See

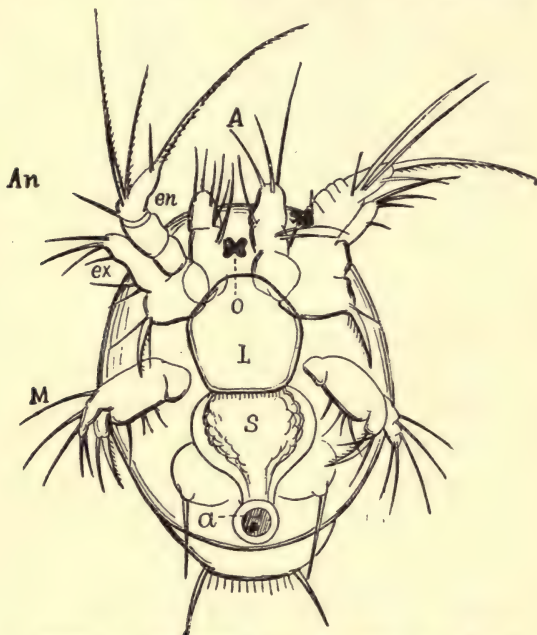


FIG. 373. — Nauplius of Entomostracan (*Canthocamptus*). See Fig. 57. A, first antenna; An, second antenna; α , anus; L, labrum; O, ocellus; S, stomach. (From Brooks, after Hoek.) Magnified.

Figures 56, 57, 58, 59. Figure 59 represents the lobster, which does not hatch as a Nauplius, but is not very unlike the prawn. These larval forms are of great interest, because they disclose the relationships of the adult forms, as the gastrula stage hints at the common relationships of all animals above Protozoa.

• 2. *Alternate Generation*

Sometimes a metamorphosis extending over several generations is required to evolve the perfect animal; "in other words, the parent may find no resemblance to himself in any of his progeny, until he comes down to the great-grandson." Thus, the jellyfish, or medusa, lays eggs which are hatched into larvæ resembling Infusoria — little transparent oval bodies covered with cilia, by which they swim about for a time till they find a resting place. One of them, for example, becoming fixed, develops rapidly; it elongates and spreads at the upper end; a mouth is formed, opening into a digestive cavity; and tentacles multiply till the mouth is surrounded by them. At this stage it resembles a hydra. Then slight wrinkles appear along the body, which grow deeper and deeper, till the animal looks like "a pine cone surmounted by a tuft of tentacles"; and then like a pile of saucers (about a dozen in number) with scalloped edges. Next, the pile breaks up into separate segments, which are, in fact, so many distinct animals; and each turning over as it is set free, so as to bring the mouth below, develops into an adult medusa, becoming more and more convex, and furnished with tentacles, circular canals, and other organs exactly like those of the progenitor which laid the original egg (Figs. 20, 374).

Here we see a medusa producing eggs which develop into stationary forms resembling hydras. The hydras then produce not only medusæ by budding in the manner described, but also other hydras like themselves by budding. All these intermediate forms are transient states of the jellyfish, but the metamorphoses can not be said to occur in the same individual. While a caterpillar *becomes* a butterfly, this hydralike individual *pro-*

duces a number of medusæ. Alternate generation is, then, an alternation of asexual and sexual methods of reproduction, one or more generations produced from buds being followed by a single generation produced

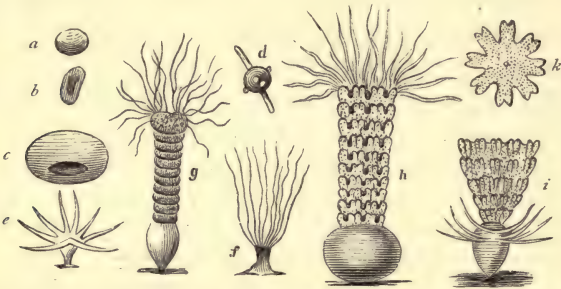


FIG. 374. — Alternate generation: *a, b, c*, ova of an *Aculeph* (*Chrysaora*); *d, e, f*, *Hydras*; *g, h*, *Hydras* with constrictions; *i*, *Hydra* undergoing fission; *k*, one of the separated segments, a free medusa.

from eggs. Often, as in the fresh-water hydra, the two kinds of generations are alike in appearance. The process is as widespread as asexual reproduction, being found mostly in sponges, coelenterates, and worms. It is also found in certain crustacea and insects. The name is sometimes limited to cases where the two kinds of generations differ in form.

3. Growth and Repair

Growth is increase of bulk, as Development is increase of structure. It occurs whenever the process of repair exceeds that of waste, or when new material is added faster than the tissues are destroyed. There is a specific limit of growth for all animals, although many of the low cold-blooded forms, as the trout and anaconda, seem to grow as long as they live. After the body has attained its maturity, *i.e.*, has fully developed, the tissues cease to grow; and nutrition is concerned solely in sup-

plying the constant waste, in order to preserve the size and shape of the organs. A child eats to grow and repair; the adult eats only to repair.¹⁷² Birds develop rapidly, and so spend most of their life full-fledged; while insects generally, fishes, amphibians, reptiles, and mammals mature at a comparatively greater age. The perfect insect rarely changes its size, and takes but little food; eating and growing are almost confined to larval life. The crust of the sea urchin, which is never shed, grows by the addition of matter to the margins of the plates. The shell of the oyster is enlarged by the deposition of new laminae, each extending beyond the other. At every enlargement, the interior is lined with a new nacreous layer; so that the number of such layers in the oldest part of the shell indicates the number of enlargements. When the shell has reached its full size, new layers are added to the inner surface only, which increases the thickness. It is the margin of the mantle which provides for the increase in length and breadth, while the thickness is derived from the whole surface. The edges of the concentric laminae are the "lines of growth." The oyster is full-grown in about five years. The bones of fishes and reptiles are continually growing; the long bones of higher animals increase in length so long as the ends (epiphyses) are separate from the shaft. The limbs of man, after birth, grow more rapidly than the trunk.

The power of regenerating lost parts is greatest where the organization is lowest, and while the animal is in the young or larval state. It is really a process of budding. The upper part of the hydra, if separated, will reproduce the rest of the body; if the lower part is cut off, it will add the rest. Certain worms may be cut into several pieces, and each part will regain what is needed to complete the mangled organism. The starfish can

reproduce its arms; the holothurian, its stomach; the snail, its tentacles; the lobster, its claws; the spider, its legs; the fish, its fins; and the lizard, its tail. Nature makes no mistake by putting on a leg where a tail belongs, or joining an immature limb to an adult animal.¹⁷³ In birds and mammals, the power is limited to the reproduction of certain tissues, as shown in the healing of wounds. Very rarely an entire human bone, removed by disease or surgery, has been restored. The nails and hair continue to grow in extreme old age.

4. *Likeness and Variation*

It is a great law of reproduction that all animals tend to resemble their parents. A member of one class never produces a member of another class. The likeness is very accurate as to general structure and form. But it does not descend to every individual feature and trait. In other words, the tendency to repetition is qualified by a tendency to variation. Like produces like, but not exactly. The similarity never amounts to identity. So that we have two opposing tendencies—the hereditary tendency to copy the original stock, and a distinct tendency to deviate from it.

This is one of the most universal facts in nature. Every development ends in diversity. All know that no two individuals of a family, human or brute, are absolutely alike. There are always individual differences by which they can be distinguished. Evidently a parent does not project precisely the same line of influences upon each of its offspring.

This variability makes possible an indefinite modification of the forms of life. For the variation extends to the whole being, even to every organ and mental characteristic as well as to form and color. It is very slight

from generation to generation ; but it can be accumulated by choosing from a large number of individuals those which possess any given variation in a marked degree, and breeding from these. Nature does this by the very gradual process of "natural selection"; man hastens it, so to speak, by selecting extreme varieties. Hence we have in our day remarkable specimens of poultry, cattle, and dogs, differing widely from the wild races.

Sometimes we notice that children resemble, not their parents, but their grandparents or remoter ancestors. This tendency to revert to an ancestral type is called *atavism*. Occasionally stripes appear on the legs and shoulders of the horse, in imitation of the aboriginal horse, which was striped like the zebra. Sheep have a tendency to revert to dark colors.

The laws governing inheritance are unknown. No one can say why one peculiarity is transmitted from father to son, and not another ; or why it appears in one member of the family, and not in all. Among the many causes which tend to modify animals after birth are the quality and quantity of food, amount of temperature and light, pressure of the atmosphere, nature of the soil or water, habits of fellow animals, etc.

Occasionally animals occur, widely different in structure, having a very close external resemblance. Barnacles were long mistaken for mollusks, polyzoans for polyps, and lamprey eels for worms. Such forms are termed *homomorphic*.

Members of one group often put on the outward appearance of allied species in the same locality ; this is called *mimicry*. "They appear like actors or masqueraders dressed up and painted for amusement, or like swindlers endeavoring to pass themselves off for well-known and respectable members of society." Thus,

certain butterflies on the Amazon have such a strong odor that the birds let them alone ; and butterflies of another family in the same region have assumed for protection the same form and color of wing, but lack the odor. So we have beelike moths, beetlelike crickets, wasplike flies, and antlike spiders ; harmless and venomous snakes copying each other, and orioles departing from their usual gay coloring to imitate the plumage, flight, and voice of quite another kind of birds. The species which are imitated are much more abundant than those which mimic them. There is also a general harmony between the colors of an animal and those of its habitation (*protective resemblance*). We have the white polar bear, the sand-colored camel, and the dusky twilight moths. There are birds and reptiles so tinted and mottled as exactly to match the rock, or ground, or bark of a tree they frequent ; and there are insects rightly named "walking sticks" and "walking leaves." These coincidences are often beneficial to the imitating species. Generally, they wear the livery of those they live on, or resemble the forms more favored than themselves.

Again, some animals which have a nauseous taste or odor, as certain caterpillars, insects, salamanders, etc., advertise the fact by being brilliantly colored and spotted (*warning coloration*), and are thus protected against other animals which would prey upon them.

5. *Homology, Analogy, and Correlation*

The tendency to repetition in the development of animals leads to some remarkable affinities. Parts or organs, having a like origin and development, and therefore the same essential structure, whatever their form or function, are said to be *homologous* ; while parts or organs corresponding in use are called *analogous*.

By *serial homology* is meant the homology existing between successive parts of one animal.

The following are examples of homology: the arms of man, the fore legs of a horse, the paddles of a whale, the wings of a bird, the front flippers of a turtle, and the pectoral fins of a fish; the proboscis of a moth, and the jaws of a beetle; the shell of a snail, and both valves of a clam. The wings of the bird, flying squirrel, and bat are hardly homologous, since the wing of the first is developed from the fore limb only; that of the squirrel is an extension of the skin between the fore and hind limbs; while in the bat the skin stretches between the fingers, and then down the side to the tail. Examples of serial homology: the arms and legs of man; the upper and lower set of teeth; the parts of the vertebral column, however modified; the scapular and pelvic arches; the humerus and femur; carpus and tarsus; the right and left sides of most animals; the dorsal and anal fins of fishes. The legs of a lobster and lizard, the wings of a butterfly and bird, the gills of a fish and the lungs of other vertebrates, are analogous. The air bladder of a fish is homologous with a lung, and analogous to the air chambers of the nautilus.

In the midst of the great variety of form and structure in the animal world, a certain harmony reigns. Not only are different species so related as to suggest a descent from the same ancestor, but the parts of any one organism are so closely connected and mutually dependent that the character of one must receive its stamp from the character of all the rest. Thus, from a single tooth it may be inferred that the animal had a skeleton and spinal cord, and that it was a carnivorous, hot-blooded mammal. Certain structures always coëxist. Animals with two occipital condyles, and non-nucleated blood corpuscles, suckle their young, *i.e.*, they are mam-

mals. All ruminant hoofed beasts have horns and cloven feet. If the hoofs are even, the horns are even, as in the ox; if odd, as in the rhinoceros, the horns are

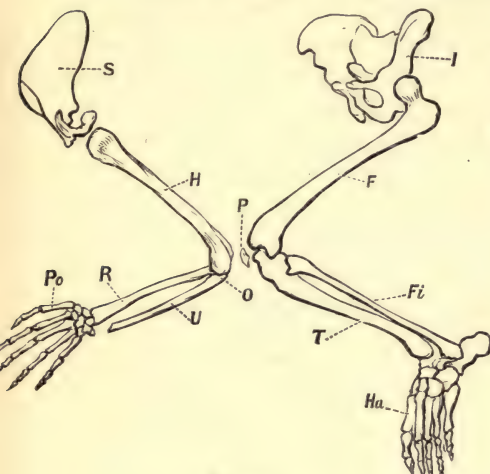


FIG. 375.

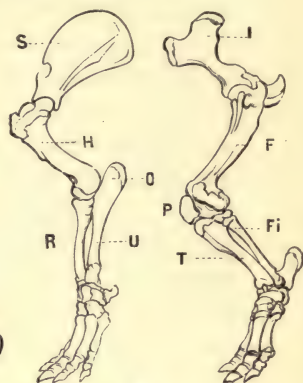


FIG. 376.

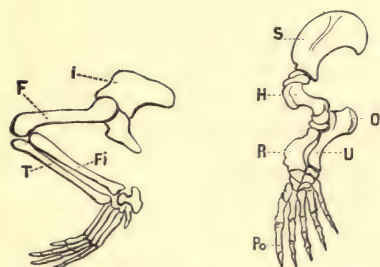


FIG. 377.

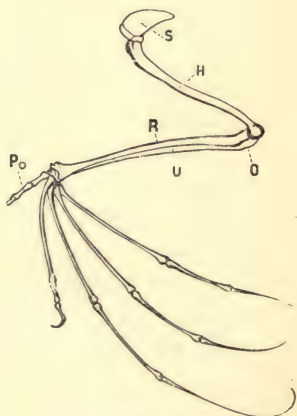


FIG. 378.

HOMOLOGIES OF LIMBS

FIG. 375. — Arm and Leg of Man, as they are when he gets down on all fours. FIG. 376. — Fore and Hind Legs of Tapir. FIG. 377. — Fore Leg of Seal and Hind Leg of Alligator. FIG. 378. — Wing of the Bat. S, scapula; I, ilium, or rim-bone of pelvis; H, humerus; F, femur; O, olecranon, or tip of the elbow; P, patella; U, ulna; T, tibia; R, radius; Fi, Fibula; Po, pollex, or thumb; Ha, hallux, or great toe. Compare the fore and hind limbs of the same animal, and the fore or hind limbs of different animals. Note the directions of the homologous segments.

odd, *i.e.*, single, or two placed one behind the other. Recent creatures with feathers always have beaks. Pigeons with short beaks have small feet; and those with long beaks, large feet. The long limbs of the hound are associated with a long head. A white spot in the forehead of a horse generally goes with white feet. Hairless dogs are deficient in teeth. Long wings usually accompany long tail feathers. White cats with blue eyes are usually deaf. A sheep with numerous horns is likely to have long, coarse wool. Homologous parts tend to vary in the same manner; if one is diseased, another is more likely to sympathize with it than one not homologous. This association of parts is called *correlation of growth*.

6. Individuality

It seems at first sight very easy to define an individual animal. A single fish, or cow, or snail, or lobster is plainly an individual; and the half of one such animal is plainly not one. But when we consider animals in colonies, like corals, it is not so easy to say whether the individual is the colony or the single polyp. Is the tree the individual, or the bud? If we say the former — the colony — what shall we say to the free buds of a hydroid colony, living independent lives, and scattered over square miles of ocean? Are they parts of one individual? If we choose the latter as our standard, we are in equal difficulty; for we must then call an individual the bud of the Portuguese man-of-war, reduced to a mere bladder or feeler, and incapable of leading an independent life. We thus find it necessary to distinguish at least two kinds of individuals — *physiological individuals*, applying that name to any animal form capable of leading an independent life; and *morphological individuals*, one of which is the total product of an egg.

Such an individual may be a single physiological individual, as the fish; or many united, as the coral stock; or many separate physiological individuals, as in the hydroids or plant lice. The single members of such a compound morphological individual are called *zooids*, or *personæ*, and are found wherever asexual reproduction takes place.

7. *Relations of Number, Size, Form, and Rank*

The animal kingdom has been likened to a pyramid, the species diminishing in number as they ascend in the scale of complexity. This is not strictly true. The number of living species known is at least 300,000, of which more than nine tenths are invertebrates. A late enumeration gives the following figures for the number of described species:—

Protozoa	4,000	Echinodermata . . .	2,300
Coelenterata	3,500	Mollusca	21,000
Vermes	5,580	Vertebrata	25,200
Arthropoda	250,000		

These figures are lower than those usually given. Of vertebrates, fishes are most abundant; then follow birds, mammals, reptiles, and amphibians. There are usually said to be about 200,000 species of insects and it is estimated that there are about 500,000 living species in the animal kingdom; about 40,000 extinct species have been described.

The largest species usually belong to the higher classes. The aquatic members of a group are generally larger than the terrestrial, the marine than the fresh-water, and the land than the aerial. The extremes of size are an Infusorium, $\frac{1}{16000}$ of an inch in diameter, and the whale, eighty-five feet long, respectively the smallest and the largest animal ever measured. The

female is sometimes larger than the male, as of the nautilus, spider, and eagle. The higher the class, the more uniform the size. Of all groups of animals, insects and birds are the most constant in their dimensions.

Every organism has its own special law of growth: a fish and an oyster, though born in the same locality, develop into very different forms. Yet a symmetry of plan underlies the structure of all animals. In the embryo, this symmetry of the two ends, as well as the two sides, is nearly perfect; but it is subsequently interfered with to adapt the animal to its special conditions of life. It is a law that an animal grows equally in those directions in which the incident forces are equal. The polyp, rooted to the rocks, is subjected to like conditions on all sides, and, therefore, it has no right and left, or fore and hind parts. The lower forms, generally, are more or less geometrical figures: spheroidal, as the sea urchin; radiate, as the starfish; and spiral, as many foraminifers. The higher animals are subjected to a greater variety of conditions. Thus, a fish, always going through the water head foremost, must show considerable difference between the head and the hinder end; or a turtle, moving over the ground with the same surface always down, must have distinct dorsal and ventral sides.

Nevertheless, there is a striking likeness between the two halves or any two organs situated on opposite sides of an axis. And, first, a *bilateral symmetry* is most common. It is best exhibited by the arthropods and vertebrates, but nearly all animals can be clearly divided into right and left sides—in other words, they appear to be double. A vertical plane would divide into two equal parts our brain, spinal cord, vertebral column, organs of sight, hearing, and smell; our teeth, jaws, limbs, lungs, etc. In fact, the two halves of every egg are identical.

There are many exceptions: the heart and liver of the higher vertebrates are eccentric; the nervous system of mollusks is scattered; the hemispheres of the human brain are sometimes unequal; the corresponding bones in the right and left arms are not precisely the same length and weight; the narwhal has an immense tusk on the left side, with none to speak of on the other; the rattlesnake has but one lung, the second remaining in a rudimentary condition; both eyes of the adult flounder and halibut are on the same side; the claws of the lobster differ; and the valves of an oyster are unequal. But all these animals and their organs are perfectly symmetrical in the embryo state.

Again, animals exhibit a certain correspondence between the fore and hind parts.¹⁷⁴ Thus, the two ends of the centipede repeat each other. Indeed, in some worms, the eyes are developed in the last segment as well as the first. In the embryo of quadrupeds, the four limbs are closely alike. But in the adult, the fore and hind limbs differ more than the right and left limbs, because the functions are more dissimilar. An extreme want of symmetry is seen in birds, which combine aerial and land locomotion.

Every animal is perfect in its kind and in its place. Yet we recognize a gradation of life. Some animals are manifestly superior to some others. But it is not so easy to say precisely what shall guide us in assorting living forms into high and low. Shall we make structure the criterion of rank? Plainly the simple jellyfish is beneath complicated man. The intricate and finished build of the horse elevates him immeasurably above the stupid snail. The repetition of similar parts, as in the worm, is a sign of low life. So also a prolonged posterior is a mark of inferiority, as the lobsters are lower than the crabs, snakes than lizards, monkeys than apes.

The possession of a head distinct from the region behind it is a sign of power. And in proportion as the fore limbs are used independently of the hind limbs, the animal ascends the scale: compare the whale, horse, cat, monkey, and man.

But shall the fish, never rising above the "monotony of its daily swim," be allowed to outrank the skillful bee? Shall the brainless, sightless, almost heartless amphioxus, a vertebrate, be allowed to stand nearer to man than the ant? What is the possession of a backbone to intelligence? No good reason can be given why we might not be just as intelligent beings if we carried, like the insect, our hearts in our backs and our spinal cords in our breasts. So far as its activity is concerned, the brain may be as effective if spread out like a map as packed into its present shape. Even animals of the same type, as vertebrates, can not be ranked according to complexity. For while mammals, on the whole, are superior to birds, birds to reptiles, and reptiles to fishes, they are not so in every respect. Man himself is not altogether at the head of creation. We carry about in our bodies embryonic structures. That structural affinity and vital dignity are not always parallel may be seen by comparing an Australian aborigine and an Englishman.¹⁷⁵

Function is the test of worth. Not mere work, however; for we must consider its quality and scope. An animal may be said to be more perfect in proportion as its relations to the external world are more varied, precise, and fitting. Complexity of organization, variety, and amount of power are secondary to the degree in which the whole organism is adapted to the circumstances which surround it, and to the work which it has to do. Ascent in the animal scale is not a passage from animals with simple organs to animals with complex organs, but from simple individuals with organs of

complex function to complex individuals with organs of simple function: the addition as we ascend being not function, but parts to discharge those functions; and the advantage gained, not another thing done, but the same thing done better. Advance in rank is exhibited, not by the possession of more life (for some animalcules are ten times more lively than the busiest man), but by the setting apart of more organs for special purposes. The higher the animal, the greater the number of parts combining to perform each function. The power is increased by this division of labor. The most important feature in this specialization is the tendency to concentrate the nervous energy toward the head (*cephalization*). It increases as we pass from lower to higher animals.

As a rule, fixed species are inferior to the free, water species to land species, fresh-water animals to marine, arctic forms to tropical, and the herbivorous to the carnivorous. Precocity is a sign of inferiority: compare the chicks of the hen and the robin, a colt with a kitten, the comparatively well-developed caterpillar with the footless grub of the bee. Among invertebrates, the male is frequently inferior, not only in size, but also in grade of organization. Animals having a wide range as to climate, altitude, or depth are commonly inferior to those more restricted; man is a notable exception.

There is some relation between the duration of life and the size, structure, and rank of animals. Vertebrates not only grow to a greater size, but also live longer than invertebrates. Whales and elephants are the longest-lived; and falcons, ravens, parrots, and geese, alligators and turtles, and sharks and pikes are said to live a century. The life of quadrupeds generally reaches its limit when the molar teeth are worn down: those of the sheep last about 15 years; of the ox, 20; of the horse, 40; of

the elephant, 100. Many inferior species die as soon as they have laid their eggs, just as herbs perish as soon as they have flowered.

8. *The Struggle for Life*

Every species of animal is striving to increase in a geometrical ratio. But each lives, if at all, by a struggle at some period of its life. The meekest creatures must fight, or die.

“There is no exception to the rule that every organic being naturally increases at so high a rate, that, if not destroyed, the earth would soon be covered by the progeny of a single pair.” If the increase of the human race were not checked, there would not be standing room for the descendants of Adam and Eve. A pair of elephants, the slowest breeder of all known animals, would become the progenitors, in seven and one-half centuries, of 19,000,000 of elephants, if death did not interfere. Evidently a vast number of young animals must perish while immature, and a far greater host of eggs fail to mature. A single cod, laying millions of eggs, if allowed to have its own way, would soon pack the ocean.

Yet, so nicely balanced are the forces of nature, the average number of each kind remains about the same. The total extinction of any one species is exceedingly rare. The number of any given species is not determined by the number of eggs produced, but by its surrounding conditions.¹⁷⁶ Aquatic birds outnumber the land birds, because their food never fails, not because they are more prolific. The fulmer petrel lays but one egg, yet it is believed to be the most numerous bird in the world.

The main checks to the high rate of increase are: *climate* (temperature and moisture), acting directly or indirectly by reducing food; and *other animals*, either

rivals requiring the same food and locality, or enemies, for the vast majority of animals are carnivorous. Offspring are continually varying from their parents, for better or worse. If feebly adapted to the conditions of existence, they will finally go to the wall. But those forms having the slightest advantage over others inhabiting the same region, being hardier or stronger, more agile or sagacious, will survive. Should this advantageous variation become hereditary and intensified, the new variety will gradually extirpate or replace other kinds. This is what Mr. Darwin means by *Natural Selection*, and Herbert Spencer by the *Survival of the Fittest*.

CHAPTER XXIV

THE DISTRIBUTION OF ANIMALS

LIFE is everywhere. In the air above, the earth beneath, and the waters under the earth, we are surrounded with life. Nature lives: every death is only a new birth, every grave a cradle. The air swarms with birds, insects, and invisible animalcules. The waters are peopled with innumerable forms, from the protozoan, millions of which would not weigh a grain, to the whale, so large that it seems an island as it sleeps upon the waves. The bed of the sea is alive with crabs, mollusks, polyps, starfishes, and Foraminifera. Life everywhere—on the earth, in the earth, crawling, creeping, burrowing, boring, leaping, running.

Nor does the vast procession end here. The earth we tread is largely formed of the *débris* of life. The quarry of limestone, the flints which struck the fire of the old Revolutionary muskets, are the remains of countless skeletons. The major part of the Alps, the Rocky Mountains, and the chalk cliffs of England are the monumental relics of bygone generations. From the ruins of this living architecture we build our Parthenons and Pyramids, our St. Peters and Louvres. So generation follows generation. But we have not yet exhausted the survey. Life cradles within life. The bodies of animals are little worlds having their own fauna and flora. In the fluids and tissues, in the eye, liver, stomach, brain, and muscles, parasites are found; and these parasites often have their parasites living on them.

Even the unicellular forms, *Stylonychia*, for example, have been found to be infested with parasitic protozoans.

Thus the ocean of life is inexhaustible. It spreads in every direction, into time past and present, flowing everywhere, eagerly surging into every nook and corner of creation. On the mountain top, in the abysses of the Atlantic, in the deepest crevice of the earth's crust, we find traces of animal life. Nature is prodigal of space, but economical in filling it.¹⁷⁷

Animals are distributed over the globe according to definite laws, and with remarkable regularity.

Each of the three great provinces, Earth, Air, and Water, as also every continent, contains representatives of all the classes; but the various classes are unequally represented. Every great climatal region contains some species not found elsewhere, to the exclusion of some other forms. Every grand division of the globe, whether of land or sea, each zone of climate and altitude, has its own fauna. In traveling over the earth and settling in new regions man has been accompanied by many animals which have established themselves and thriven in the land of their adoption. For example, the house, or "English," sparrow has been brought to America, and the sparrow and rabbit to New Zealand. Hence, it is necessary to distinguish between the *native* or *indigenous* fauna, and the *introduced* fauna, the latter depending upon human agency. In spite of the many causes tending to disperse animals beyond their natural limits, each country preserves its peculiar zoölogical physiognomy.

The space occupied by the different groups of animals is often inversely as the size of the individuals. Compare the coral and elephant.

The fauna now occupying a separate area is closely allied to the fauna which existed in former geologic

times. Thus, Australia has always been the home of marsupials, and South America of edentates.

It is a general rule that groups of distinct species are circumscribed within definite, and often narrow, limits. Man is the only cosmopolitan; yet even he comprises several marked races, whose distribution corresponds with the great zoölogical regions. The natives of Australia are as grotesque as the animals. Certain brutes likewise have a great range: thus, the puma ranges from Canada to Patagonia; the muskrat, from the Arctic Ocean to Florida; the ermine, from Bering Strait to the Himalayas; and the hippopotamus, from the Nile and Niger to the Orange River.¹⁷⁸

Frequently, species of the same genus, living side by side, are widely different, while there is a close resemblance between forms which are antipodes. The mud eel of South Carolina and menobranchus of the Northern States have their relatives in Japan and Austria. The American tapir has its mate in Sumatra, the llama is related to the camel, and the opossum to the kangaroo.

The chief causes modifying distribution are temperature, topography, ocean and wind currents, humidity, and light. To these may be added the fact that animals are ever intruding on each other's spheres of existence. High mountain ranges, wide deserts, and cold currents in the ocean are impassable barriers to the migration of most species. Thus, river fish on opposite sides of the Andes differ widely, and the cold Peruvian current prevents the growth of coral at the Galapagos Islands. So a broad river, like the Amazon, or a deep, narrow channel in the sea, is an effectual barrier to some tribes. Thus, Borneo belongs to the Indian region, while Celebes, though but a few miles distant, is Australian in its life. The faunæ of North America, on

the east coast, west coast, and the open plains between, are very different.

Animals dwelling at high elevations resemble those of colder latitudes. The same species of insects are found on Mount Washington, and in Labrador and Greenland.

The range does not depend upon the powers of locomotion. The oyster extends from Halifax to Charleston, and the snapping turtle from Canada to the equator; while many quadrupeds and birds have narrow habitats.

The distribution of any group is qualified by the nature of the food. Carnivores have a wider range than herbivores.

Life diminishes as we depart from the equator north or south, and likewise as we descend or ascend from the level of the sea.

The zones of geography have been divided by zoölogists into narrower provinces. Three regions in the sea are recognized: the Pelagic or surface region; the Littoral, between tide marks strictly but often interpreted to conclude depths to forty fathoms; and the Abyssal, extending from the Littoral to the greatest depths of the ocean. Every marine species has its own limits of depth. It would be quite as difficult, said Agassiz, for a fish or a mollusk to cross from the coast of Europe to the coast of America as for a reindeer to pass from the arctic to the antarctic regions across the torrid zone. Marine animals congregate mainly along the coasts of continents and on soundings. The meeting place of two maritime currents of different temperatures, as on the Banks of Newfoundland, favors the development of a great diversity of fishes.

Every great province of the ocean contains some representatives of all the subkingdoms. Deep-sea life

is diversified, though comparatively sparse. Examples of all the five invertebrate divisions were found in the Bay of Biscay, at the depth of 2435 fathoms.¹⁷⁹

Distribution in the sea is influenced by the temperature and composition of the water and the character of the bottom. The depth acts indirectly by modifying the temperature. Northern animals approach nearer to the equator in the sea than on the land, on account of cold currents. The heavy aquatic mammals, as whales, walruses, seals, and porpoises, are mainly polar.

The land consists of the following somewhat distinct areas: the Neotropic, comprising South America, the West Indies, and most of Mexico; the Nearctic, including the rest of America; the Palearctic, composed of the eastern continent north of the Tropic of Cancer, and the Himalayas; the Ethiopian, or Africa south of the Tropic of Cancer; the Oriental, or India, the southern part of China, the Malay Peninsula, and the islands as far east as Java, Borneo, and the Philippine Islands; and the Australian, or the eastern half of the Malay Islands and Australia. These are the regions of Sclater and Wallace. Other writers unite the northern parts of both hemispheres into one region, and the Oriental with the Ethiopian regions.

Life in the polar regions is characterized by great uniformity, the species being few in number, though the number of individuals is immense. The same animals inhabit the arctic portions of the three continents; while the antarctic ends of the continents, Australia, Cape of Good Hope, and Cape Horn, exhibit strong contrasts. Those three continental peninsulas are, zoologically, separate worlds. In fact, the whole southern hemisphere is peculiar. Its fauna is antique. Australia possesses a strange mixture of the old and new.

South America, with newer mammals, has older reptiles; while Africa has a rich vertebrate life, with a striking uniformity in its distribution. Groups, old geologically and now nearly extinct, are apt to have a peculiar distribution; as the Edentata in South America, Africa, and India; the marsupials in Australia and America; the Ratitæ in South America, Africa, Australia, and New Zealand.

In the tropics, diversity is the law. Life is more varied and crowded than elsewhere, and attains its highest development.

The New World fauna is old-fashioned, and inferior in rank and size, compared with that of the eastern continents.

As a rule, the more isolated a region the greater the variety. Oceanic islands have comparatively few species, but a large proportion of endemic or peculiar forms. Batrachians are absent, and there are no indigenous terrestrial mammals. The productions are related to those of the nearest continent. When an island, as Britain, is separated from the mainland by a shallow channel, the mammalian life is the same on both sides.

Protozoans, coelenterates, and echinoderms are limited to the waters, and nearly all are marine. Sponges are mostly obtained from the Grecian Archipelago and Bahamas, but species not commercially valuable abound in all seas. Coral reefs abound throughout the Indian Ocean and Polynesia, east coast of Africa, Red Sea, and Persian Gulf, West Indies, and around Florida; and corals which do not form reefs are much more widely distributed, being found as far north as Long Island Sound and England. Crinoids have been found, usually in deep sea, in very widely separated parts of the world—off the coast of Norway, Scotland, and Portugal, and near the East and West Indies. The

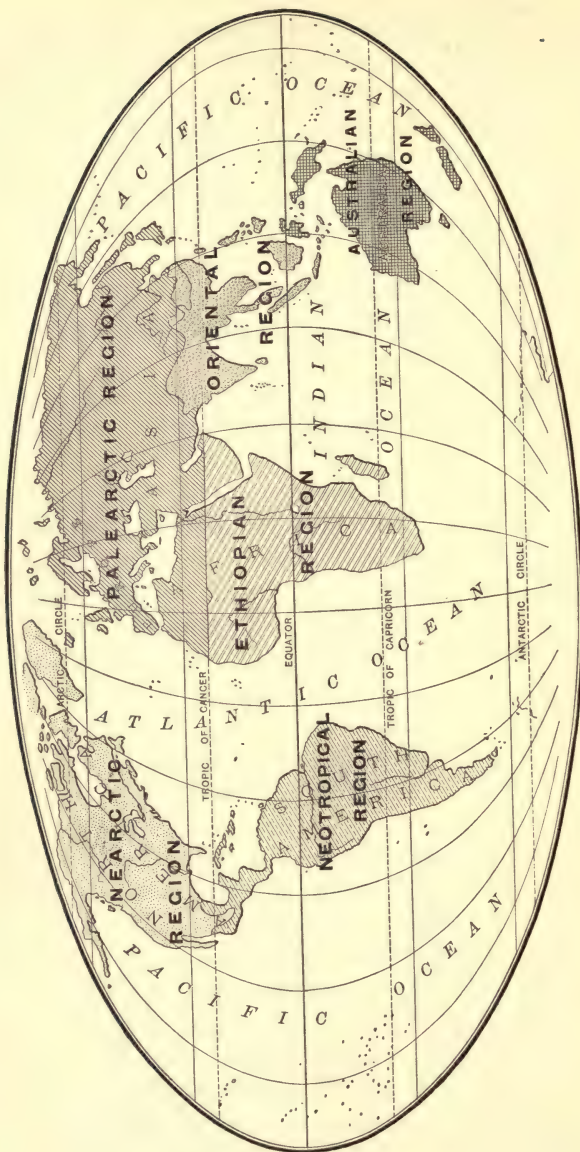


FIG. 379. — The Zoogeographical Regions.

other echinoderms abound in almost every sea; the starfishes chiefly along the shore, the sea urchins in the Littoral zone, and the sea slugs around coral reefs. Worms are found in all parts of the world, in sea, fresh water, and earth. They are most plentiful in the muddy or sandy bottoms of shallow seas. Living brachiopods, though few in number, occur in tropical, temperate, and arctic seas, and from the shore to great depths. Polyzoa have both salt and fresh water forms, and annelids include land forms, as the earthworm and some leeches.

Mollusks have a world-wide distribution over land and sea. The land forms are restricted by climate and food, the marine by shallows or depths, by cold currents, by a sandy, gravelly, or muddy bottom. The bivalves are also found on every coast and in every climate, as well as in rivers and lakes, but do not flourish at the depth of much more than two hundred fathoms. The fresh-water mussels are more numerous in the United States than in Europe, and west of the Alleghanies than east. The seashells along the Pacific coast of America are unlike those of the Atlantic, and are arranged in five distinct groups: Aleutian, Californian, Panamic, Peruvian, and Magellanic. On the Atlantic coast, Cape Cod and Cape Hatteras separate distinct provinces. Of land snails, *Helix* has an almost universal range, but is characteristic of North America, as *Bulimus* is of South America, and *Achatina* of Africa. The Old World and America have no species in common, except a few in the extreme north.

The limits of insects are determined by temperature and vegetation, by oceans and mountains. There is an insect fauna for each continent, and zone, and altitude. The insects near the snow line on the sides of mountains in the temperate region are similar to those in polar lands. The insects on our Pacific slope resemble those

of Europe, while those near the Atlantic coast are more like those of Asia. Less than a score of insects are known to live in the sea.

The distribution of fishes is bounded by narrower limits than that of other animals. A few tribes may be called cosmopolitan, as the sharks and herrings; but the species are local. Size does not appear to bear any relation to latitude. The marine forms are three times as numerous as the fresh-water. The migratory fishes of the northern hemisphere pass to a more southern region in the spring, while birds migrate in the autumn.

Living reptiles form but a fragment of the immense number which prevailed in the Middle Ages of geology. Being less under the influence of man, they have not been forced from their original habitats. None are arctic. America is the most favored spot for frogs and salamanders, and India for snakes. Australia has few batrachians, and two thirds of its snakes are venomous. In the United States, only about one eighth of the species are venomous. Frogs, snakes, and lizards occur at elevations of over fifteen thousand feet. Crocodiles, and most lizards and turtles, are tropical.

Swimming birds, which constitute about one fourteenth of the entire class, form one half of the whole number in Greenland. As we approach the tropics, the variety and number of land birds increase. Those of the torrid zone are noted for their brilliant plumage, and the temperate forms for their more sober hues, but sweeter voices. India and South America are the richest regions. Hummers, tanagers, orioles, and toucans are restricted to the New World. Parrots are found in every continent except Europe; and woodpeckers occur in every region, save in Australia.

The vast majority of mammals are terrestrial; but cetaceans and seals belong to the sea, otters and beavers

delight in lakes and rivers, and moles are subterranean. As of birds, the aquatic species abound in the polar regions. Marsupials inhabit two widely separated areas—America and Australia. In the latter continent they constitute two thirds of the fauna, while nearly all placental mammals, except bats and a few rats and squirrels, are wanting. Excepting a few species in South Africa and South Asia, edentates are confined to tropical South America. The equine family is indigenous to South and East Africa and Southern Asia, while their fossil remains are abundant in both North and South America. In North America, rodents form about one half the number of mammals; there are very few species in Madagascar. Ruminants are sparingly represented in America. Carnivores flourish in every zone and continent. The prehensile-tailed monkeys are strictly South American; while the anthropoid apes belong to the west coast of Africa, and to Borneo and Sumatra. Both monkeys and apes are most abundant near the equator; in fact, their range is limited by the distribution of palms.

CHAPTER XXV

THE ORIGIN OF ANIMAL SPECIES

THE origin of the immense number of species of plants and animals inhabiting the earth has been a matter of speculation among naturalists and philosophers for many centuries. One theory has held that each species was created separately, while the other, known as the Theory of Evolution, maintains that living forms are derived by natural processes of descent from species that inhabited the earth in earlier times; that is, the ancestral forms became extinct owing to changing conditions of climate, food supply, enemies, and other factors, and their descendants in the course of many generations have become modified in bodily structure and function, these changes leading to the development, or *evolution*, of the numerous species now living. The evidence in favor of the latter theory is so strong that it is now accepted by scientific men as the true explanation of the mode of origin of all known organisms.

Although the idea of evolution has been more or less definitely held by various naturalists since the time of Aristotle (384–322 B.C.), others, even as recently as Linnaeus (1707–1778) and Cuvier (1768–1832), have insisted that species are immutable, or unchanging in characteristics. Bonnet (1720–1793) was the first among later zoölogists to suggest that variations of climate, nourishment, and other features of the environment might produce new species, and to use the term *evolution* in its modern sense; but he adduced no important facts to

support his theory, and it failed to meet with the approval of his contemporaries. Lamarck (1744-1829) afterward adopted this view, collected many facts in its favor, and also advanced the hypothesis, in 1801, that the use and disuse of organs would cause structural modifications in them, producing either increased development or atrophy of parts. These modifications, being inherited by successive generations, would eventually become characteristic of new species thus evolved from the older ones. Lamarck's theory was opposed by Cuvier, the greatest comparative anatomist and paleontologist of his time, who insisted that, if the theory were true, there ought to be among fossils transition forms connecting the extinct with the living species, but that no such forms were known, nor could a process be suggested by which transition could take place. Under Cuvier's leadership the belief became current among geologists that the earth has passed through a series of catastrophes or cataclysms which destroyed all living things, and that it has successively been repeopled with new forms quite unlike those which had perished. The Lamarckian theory passed into obscurity, and was not seriously considered again until it was brought forth for comparison with Darwin's theory of natural selection. The opinions of geologists regarding cataclysms underwent a change after Hutton (1726-1797) urged that in order to understand how the present condition of the earth came about, the changes now taking place must be studied. This view was later vigorously upheld and extended by Lyell (1797-1875), who contended that cataclysms have never occurred, but that the earth has gradually reached its present state through the action of natural forces which are still in operation. Thus the way was prepared for the appearance of the theory which, elaborated and maintained by numerous observa-

tions, was propounded by Charles Darwin (1809–1882) in his “Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life,” published in 1859. Darwin had served as naturalist on the British exploring ship *Beagle* on a five years’ cruise (1832–1837) around the world, and “was much struck with certain facts in the distribution of the organic beings inhabiting South America, and in the geological relations of the present to the past inhabitants of that continent.” After his return home, twenty additional years were spent in collecting facts, making further observations and experiments, and in pondering the theory before he ventured to publish his results and to state what he regarded as the factors concerned in the process of evolution. A similar conclusion had been reached, simultaneously and independently, by Alfred Russell Wallace (1823–), who had travelled extensively in South America and the Malay Archipelago, and, like Darwin, had become convinced of the certainty of evolution, and sought for its explanation.

As held by Darwin, the theory of evolution, together with the causes of the process, may be briefly stated as follows :—

(1) *Organisms tend to produce a great many more offspring than can survive.* Linnæus showed that the number of living descendants of an annual plant which produced only two seeds each year would, at the end of twenty years, be over a million. There is, however, no plant known to be so unproductive. With reference to the elephant, regarded as the slowest of breeders, producing at the age of thirty a pair of young, and a pair every thirty years thereafter, and living to be one hundred years old, Darwin computed that at the end of 750 years there would be about nineteen million living elephants all descended from the first pair. Individual insects lay

hundreds, and fishes millions, of eggs. If all the young were to survive, the earth would soon be unable to supply sufficient food and standing-room.

(2) *In spite of this tendency to increase inordinately, the number of animals remains, on the whole, stationary.* Even though there may be an enormous temporary increase in the number of certain animals, as in "plagues of grasshoppers," normal conditions are soon restored by natural agencies. Eggs and young are devoured by older animals. Disease, old age, parasites, enemies, storms, floods, cold, heat, drought, and famine are responsible for the death of so many individuals that comparatively few young animals of any species live to maturity.

(3) *There results, consequently, severe competition for the necessities of life, a veritable struggle for existence.* In order to thrive, animals need food, shelter from the elements, protection from enemies, and freedom from molestation while rearing their young. Deprivation of any of these is likely to be followed by serious results for the animals as individuals and for the race as a whole. The introduction of sheep has made it impossible for cattle to live on some of the Western ranges, because the sheep crop the grass so closely that there is not enough left to feed the cattle. The "English," or house, sparrow appropriates the best protected nesting places, raises several broods each season, eats whatever food is available, and remains the year round without migrating. By reason of these habits it has been victorious in the contest for the places formerly occupied by native birds. The struggle for existence is most keen between closely related forms, since each will naturally want what the other desires. Until about two centuries ago the black rat was the common rat of Europe. Since then it has been driven out by the brown rat, a larger and stronger species.

(4) *There is more or less variation even between closely related animals.* Two individuals from the same litter, for instance, always differ somewhat from each other, as well as from all their relatives, in shape, size, vigor, intelligence, and other qualities. Human beings, domesticated or wild animals, birds, shells, or insects are never so much alike that differences between individuals of the same kind cannot be detected. Wings and tails of birds of the same species have been found in some individuals to be twenty per cent longer, and in others as much shorter, than the average. Variations, then, are by no means necessarily minute, but may be considerable in amount. Nor is variation confined to structure alone, for it may also affect habits. Chimney swifts built their nests in hollow trees before the country was settled. A New Zealand parrot which, before the occupation of the island by Europeans, lived on honey, insects, and fruits, began to pick at meat and skins hung up to dry by the settlers, and thus acquired a taste for flesh. During the past fifty years its carnivorous propensities have increased to such an extent as to lead the bird to attack living sheep. So destructive has it become that stringent measures have been taken for its extermination. In animals under domestication variation is the rule. The numerous breeds of cattle, horses, swine, fowls, pigeons, dogs, cats, rabbits, canary birds, and in fact of all domesticated animals, have been derived from a few ancestral forms. Breeders have taken advantage of peculiarities arising by variation; and by a process of selecting and breeding only from those individuals which show the peculiarity, have finally succeeded in fixing it more or less permanently, so that the young of these animals may possess it in an even more exaggerated form than their parents. In nature variations occur to such an extent, particularly in large and dominant genera, as to give rise to many doubtful species,

or forms which are intermediate between typical species.

The causes of variability are at present very imperfectly understood, but it is probable that climate, nourishment, and physiological activity, as well as other factors, have an influence on the process.

(5) *Even though animals may be inclined to vary, there is a marked tendency to inherit the characteristics of their parents.* Every animal bears a close resemblance to others of its kind. It is due to this tendency that structural and physiological characteristics once originated are perpetuated. The breeder depends upon it to keep his varieties "true" to the original stock. Whether or not characters acquired during the lifetime of an individual are transmitted by heredity to the offspring is still an unsettled problem. Denial of the probability of such inheritance is a fundamental theory in the Weismannian school of evolutionists. There seems to be no doubt, however, that congenital characters are inherited. Should variations appear, they are likely to be preserved to the race by heredity. The essential nature of the process, as in variation, is not known. To explain the phenomena of heredity, Darwin proposed the theory of *pangeneses*, which holds that particles or gemmules from all the different parts of the body are collected into the reproductive cells and through these are transmitted to the offspring and help to modify the characteristics of the latter. This theory has never been generally accepted.

(6) *The preservation or survival of those individuals inheriting the variations which are most advantageous in the struggle for existence is due to natural selection.* Among all the variations appearing in the individuals of a race some are likely to be advantageous, others the opposite. An antelope with slightly longer legs or with

more agility than other members of the herd would be better able to escape his enemies, and consequently to live longer and leave more offspring than his less fortunate companions. Of his progeny some would probably inherit the peculiarity, and it would thus be transmitted from generation to generation to the evident advantage of the race. In time the variation would become a definitely fixed and constant character, serving to distinguish all the individuals possessing it as a *species*. It is by a process of *artificial selection* that breeders choose among domestic animals those individuals which possess a character which it is desired to perpetuate, as long wool in sheep, speed in race horses, strength in draught horses, peculiarly shaped jaws in bull dogs, vocal powers in canary birds, and so on. By breeding only from those individuals which show the desired character, the latter may not only be perpetuated but also intensified in degree. This is shown by all domesticated animals and cultivated plants. To the process by which favorable variations are selected and perpetuated among wild animals, Darwin gave the name of *natural selection*. By his hypothesis the phenomenon of the evolution of organic forms is due to the natural selection of favorable variations and their preservation by heredity.

The test of the validity of a theory lies in its ability to interpret and coördinate observed facts, and when Darwin's hypothesis was applied to the elucidation of the observations collected by the students of morphology, paleontology, embryology, and other aspects of the study of animal life, it brought order out of chaos, and each of these sciences was seen to contain a mass of evidence in favor of the theory of descent with modification.

(1) *Evidence from Classification*. — As has been shown

in Part I, animals are divided according to their structural resemblances into groups of varying degrees of affinity, as branch, class, order, genus, and species. A pictorial representation of the scheme of classification would have the form of a genealogical tree (Fig. 197), the relative positions of whose branches would indicate the degree of relationship among the different groups. This scheme implies that there is actual genetic relationship and community of descent of all animal forms, the Metazoa from the Protozoa, the air-breathing vertebrates from fishlike ancestors, the birds and mammals from reptilian prototypes. There is thus evolution of the more complex from forms of simpler structure. The underlying principle of classification is heredity, or community of descent, as indicated by family likeness. After trying many other structural features as means of classification systematic zoölogists found that the surest guides in determining relationship are frequently organs of little or no assignable physiological importance. There was no explanation of this seeming paradox until it was seen that, according to Darwin's theory, such organs are not likely to undergo change, since they are apparently not of vital importance to the possessor and are handed down through successive generations little, if at all, modified, however much the rest of the body may have changed in becoming adapted to its environment.

(2) *Evidence from Morphology.* — The comparative anatomy of animals furnishes some of the strongest evidence in favor of the theory of evolution. Note, for instance, the increasing complexity of form and function as the various branches are passed in review — the single-celled Protozoa, showing colony formation in the higher orders with differentiation in form and function among the members, as *Zoöthamnium*; the loosely cellular sponges,

the lowest of the Metazoa, long considered to be colonies of Protozoa, so ill defined are their layers of tissue; the two-layered cœlenterates whose bodies contain but a single cavity with one opening serving for ingestion and egestion; the "worms," with a body consisting, except in some of the parasitic and degenerate forms, of three layers of tissue (ectoderm, mesoderm, and endoderm), with an alimentary canal having both inlet and outlet, a well-defined nervous system, and, in the higher orders, a segmented body; the arthropods, with their segments showing a tendency to become grouped into distinct regions, with jointed appendages for performing functions, and with respiratory organs, in the higher groups, for breathing air directly; the vertebrates, beginning with forms which have the merest trace of a notochord, and progressing through the lower fishes with cartilaginous skeletons, small brains, and two-chambered hearts, to the amphibia and reptiles, with bony skeletons, larger brains, and three-chambered hearts, and finally to the warm-blooded birds and mammals, with four-chambered hearts, and with brains and nervous systems far superior in size, structure, and function to those of all other groups. This hasty review does not, by any means, take cognizance of all the structural features that might be mentioned, but only draws attention to some of the most obvious characters which show progressive change from lower to higher forms.

The metameric arrangement of the bodies of the annulata, in which each segment is a more or less perfect repetition of the preceding and succeeding segments, is again recognizable, though less plain, in certain structures in the bodies of crustaceans and insects, and is very obvious in the chordates from fishes to man, as the vertebræ and pairs of ribs, the muscle plates and

pairs of muscles, the spinal nerves and ganglia, the intercostal arteries and veins.

A comparison of such dissimilar organs as the wing of the bat and the bird, the flipper of the seal, the pectoral fin of the fish, the hoof of the horse, and the hand of man shows evidence of genetic relationship in that all are constructed on one fundamental plan, which has been modified to meet the needs of different environments.

The testimony of rudimentary organs is also in favor of the theory of descent with modification. The embryo of the whalebone whale has teeth, but they never cut the gum. Their presence is explainable only on the hypothesis that this animal is a descendant of some form that had functional teeth. Nearly half of the beetles inhabiting the wind-swept island of Madeira have such rudimentary wings that flight is impossible, though there is no doubt that these insects were once capable of flying, since the nearest related species which live on the mainland have fully developed wings. In this case, inability to fly is a distinct advantage, because it renders the insect less likely to be blown out to sea and drowned. The presence of rudimentary and functionless eyes in cave-inhabiting animals indicates descent from ancestors having perfect visual organs.

(3) *Evidence from Embryology.*—Of the many important facts which this branch of science offers in support of the theory of evolution, only a few can be mentioned here. It has been learned that higher animals in the course of their embryonic development pass through stages which are permanent conditions in lower forms. Thus the bird and the mammal, though they never possess gills in their adult life, have at an early stage of existence a series of openings, gill slits, in the side of the neck, corresponding to the gill openings of

the fish, with a system of blood vessels similar to those in the fish's gills. These openings afterward close and disappear, and the most of the blood vessels waste away. Thus, a condition which is permanent in the fish is only transitory in the higher vertebrates, and it can be explained only on the supposition that during their development these forms repeat the phases through which their ancestors passed in the course of their evolution. Embryology thus corroborates paleontology in showing that the earliest vertebrates were fishlike. All of the vertebrates possess at a certain period of their embryonic life a notochord or rod of cartilage, which is later replaced by a vertebral column in all forms except *Amphioxus*, in which the organ persists. This indicates that vertebrates are descended from an amphioxus-like ancestor. Until their embryological history was learned, Ascidians were considered to be mollusks. The discovery of a rudimentary notochord at an early stage of their development showed that they are closely allied to the vertebrates. The adult halibut, turbot, sole, and other "flat fish" have both eyes on the same side of the head. In the embryonic stage the eyes are placed as in other fishes, showing that in their ancestors the eyes were in the usual position. A West Indian frog, *Hyla*, which lays eggs on land, passes through its tadpole stage in the egg. It has a large tail, like the ordinary tadpole, and gill slits in place of functional gills. The tail wastes away almost entirely, and lungs are developed before hatching occurs, the young animal thus entering upon its terrestrial mode of life unhampered by organs suited only to an aquatic existence. Its development shows that it is descended from ancestral forms which had both tail and gills.

The tendency of animals to pass through stages of development in which they temporarily exhibit features

which are permanent characteristics of forms lower than themselves, is the basis of the Recapitulation Theory, which holds that each animal bears the marks of its own ancestry and reveals its parentage in its own development.

(4) *Evidence from Paleontology.* — Although only a very small part of the earth's crust has been examined, the fossil animal remains already found furnish the primary and most direct evidence in favor of the theory of descent with modification, and they show that the process began as far back in geological history as they can be traced. The conclusions reached from the study of fossils may be stated in the words of the great paleontologist Zittel: (1) All stratified sedimentary rocks (with the exception of metamorphic rocks) inclose, more or less richly, fossils, and thus prove that the earth, for an immeasurable length of time before the appearance of man, was inhabited by organisms. (2) Fossils of the oldest and deepest strata represent extinct species, and for the most part extinct genera; only in the more recent strata are found forms which are identical with those now living. The deeper down we penetrate in the series of strata, the more divergent are the fossils from the forms now living; and, on the contrary, rising from the earliest to the more recent formations there is a continuously increasing resemblance to the present creation. (3) The different fossil faunas and floras follow each other the world over in the same regular sequence; the formations stratigraphically nearer to each other contain the most similar fossils, and those most separated in age present the greater differences. (4) Constant change characterizes the evolution of the organic creation. Species of one geological formation are either completely or partly replaced by other species in the next superimposed strata. (5) Each species, like

the individual, has a certain shorter or longer life period, after which it perishes, never to reappear.*

The genealogical history, or line of descent, of several animals has been very completely established since fossils came to be studied in the light of the theory of evolution. The ancestry of the horse has been traced through forms which follow one another in linear series from remote geological periods. The earliest form was about as large as a sheep and had five toes and short molar teeth, with a comparatively simple arrangement of the ridges on their crowns. This was succeeded by four-toed, three-toed, and eventually the single-toed horse of modern times. The diminution in the number of the digits was accompanied by gradually increasing stature and growing complexity of the crown patterns of the teeth. An even more complete series of remains from the bed of an ancient lake establishes the genealogy of the fresh-water snail, *Planorbis*. "In passing from the lowest to the highest strata the species change greatly and many times, the extreme forms being so different that, were it not for the intermediate forms, they would be called not only different species, but different genera. And yet the gradations are so insensible that the whole series is nothing less than a demonstration, in this case at least, of origin of species by derivation with modifications."† Other series show the evolution of the horn-bearing ruminants from hornless ancestors. Casts of the brain cavities of the early mammals show that their brains were much smaller than those of living species and had fewer, if any, convolutions.

Of the "missing links" none is more instructive than

* Quoted from Williams's "Geological Biology," pp. 82-83.

† Quoted from Le Conte's "Evolution and its Relations to Religious Thought," pp. 254-255.

Archæopteryx, which occupies a position between the reptiles and the birds. Its fossil remains show its reptilian characters in the separate digits on the fore limb, the elongated tail consisting of many vertebræ, and the well-developed teeth in each jaw. Its most prominent avian features were its wings and covering of feathers. The discovery of extinct toothed birds served to make the connection between birds and reptiles complete.

(5) *Evidence from Geographical Distribution.* — When the faunas of the different continents are compared, they are found to be very unlike. Even in those regions which have much the same climate and other physical conditions, as South Africa, South America, and Australia, the faunas are not correspondingly similar. On the other hand, when the animals inhabiting the northern part of South America are compared with those living in the southern portion, there are found to be closer resemblances than in the instances just noted, even though the climatal differences are much greater. A similar statement could be made regarding other great continental areas. There is no native species of mammal common to Europe, America, and Australia, though introduced species thrive. Rabbits, for example, taken from Europe to Australia have multiplied to such an extent as to have become veritable pests. Evidently differences of climate do not alone account for the present geographical distribution of animals. Great barriers, as oceans, lofty mountain ranges, and deserts, separate faunas, though the differences are not so great as in the case of distinct continents. Again, while it is noted that different regions of a continent are inhabited by distinct species, it is found that these species are more nearly related among themselves than to the species of other continents. For instance, the humming birds, near relatives of the sunbirds of Africa and Asia, number about

four hundred species, and are all confined to the Western Hemisphere. The explanation of this fact is that they originated in this part of the world, and are too small and weak to make the long flight necessary to reach other regions.

Islands are usually populated by forms brought from the nearest mainland, unless the ocean currents are such as to bring animals from places more remote. Such islands as are separated from a neighboring continent by deep channels have a fauna more archaic and primitive than that found on the mainland. Australia and New Zealand are thought to have been separated from the nearest larger bodies of land for long geological periods, and possibly since the time of their formation. Their faunas are of a very primitive type, including the marsupials, one of the oldest and least highly developed orders of mammals; the monotremes, *Ornithorhynchus* and *Echidna*, the lowest representatives of the same class, and *Apteryx*, the lowest of living birds. Isolated on their island continents and free from the competition of higher forms, and especially from the attacks of carnivores, these lowly organized and almost defenseless species have retained to a marked degree the characteristics of their remote ancestors. Where the separation of island and continent has taken place more recently, or where the channel is shallow or narrow, there is greater resemblance between their faunas. Thus, wild animals of Great Britain are quite the same as those of western Europe. The number of species found on islands is usually small as compared with those inhabiting an equal continental area, because the number of ancestral forms which have been carried to the island by currents, wind, and man is likely to be small.

The animals found on high mountain peaks and ranges are distinctly allied to arctic forms. On the northward

retreat of the great ice sheet which, during the last glacial period, covered much of Europe, Asia, and North America, these boreal species were left stranded in, and have since been confined to, regions having arctic characteristics. Species which are closely related to one another are known to inhabit mountain peaks, separated by long stretches of lowland, on which animals of the arctic type could not possibly exist. Their presence can be explained only on the supposition that they are descended from forms which inhabited the entire region during the glacial period and that when the climate became warmer these animals retreated to the cold mountain tops. Many oceanic islands are destitute of batrachians and terrestrial mammals, these animals not having had an independent evolution in these localities, nor being able to make their way out from the mainland. On the other hand, aerial mammals, as bats, are of nearly universal distribution.

It is generally admitted that each species originated in one locality and, by migration, spread into neighboring regions, becoming modified as dispersal brought it into different environments, thus giving rise to variations which ultimately resulted in the development of a number of more or less closely related species.

Such are the main features of the theory of evolution and of Darwin's explanation of the process through variation, heredity, and natural selection. As a subordinate factor should be mentioned his theory of *sexual selection*, by which is meant that the choice of mates, among the higher animals at least, is largely determined by such physical characteristics as strength, beauty of form, coloration, and vocal powers. Those individuals, for instance, which possessed any of these pleasing characteristics in a higher degree than their companions would be more likely to find mates and to leave de-

scendants. On this theory Darwin accounted for the development of antlers, the beautiful colors of birds, fishes, and insects, and the calls of various animals.

While evolution has come to be regarded as a fact of as much certainty as gravitation, and natural selection, with variation and heredity, to be accepted by many naturalists as the process by which evolution is brought about, not all are agreed as to the importance to be attributed to the Darwinian factor, *i.e.* natural selection. Darwin himself regarded it as "the main but not the exclusive means of modification." Search for additional means has been made and is still being prosecuted. Thus *consciousness* is claimed to be a controlling agent in the use and disuse of organs, in the adoption of new habits, in the selection of environment, in the choice of mates, and so on. *Isolation* due to the geographical separation of individuals or of species, or to the inability of forms to interbreed (*physiological isolation*) has been suggested as another cause of modification. Still another factor, *organic selection*, has been proposed. It is claimed for this that the adoption of a new habit by an animal will lead to the development of structures adapted to the habit, and thus produce changes in specific differences.

The most important addition to the philosophy of organic evolution made since Darwin is Weismann's theory of the continuity of the germ plasm, which maintains, supported by facts of observation, that the essential germinal substance is transmitted from generation to generation through the reproductive cells. Whether or not this material—the bearer of heredity—may be influenced by structural and physiological changes occurring in the species, and thus be transmitted to descendants, is a question which has not yet been definitely answered.

NOTES

¹ The complete and elaborate natural history of a single species or limited group is called a *Monograph*, as Darwin's "Monograph of the Cirripedia." A *Memoir* is not so formal or exhaustive, giving mainly original investigations of a special subject, as Owen's "Memoir on the Gorilla."

² Before the time of Linnæus, the ladybug, *e.g.*, was called "the Coccinella with red coleopters having seven black spots." He called it *Coccinella septem-punctata*.

³ Mondino (1315) and Berenger (1518) of Bologna, and Vesalius of Brussels (1543), were the first anatomists. Circulation of the blood discovered by Harvey, 1616. The lacteals discovered by Asellius, 1622, and the lymphatics by Rudbek, 1650. Willis made the first minute anatomy of the brain and nerves, 1659. The red blood corpuscles were discovered by Swammerdam, 1658. Infusoria first observed by Leeuwenhoek, 1675; the name given by Müller, 1786. Swammerdam was the founder of Entomology, 1675. Comparative anatomy was first cultivated by Perrault, Pecquet, Duverney, and Méry, of the Academy of Paris, the latter part of the seventeenth century. Malpighi, the founder of structural anatomy, was the first to demonstrate the structure of the lungs and skin, 1661. About the same time, Ray and Willoughby first classified fishes on structural grounds. Foraminifers were seen by Beccarius one hundred and fifty years ago; but their true structure was not demonstrated till 1835, by Dujardin. Peyssonel published the first elaborate treatise on Corals, 1727. Haller was the first to distinguish between contractility and sensibility, 1739. White blood corpuscles discovered by Hewson in 1775. Spallanzani was the first to demonstrate the true nature of the digestive process, 1777. Cuvier and Geoffroy, in 1797, proposed the first natural classification of animals. Before that, all invertebrates were divided into insects and worms. Lamarck was the first to study mollusks, 1800; before him, attention was confined to the shell. He separated spiders from insects in 1812. The law of correlation enunciated by Cuvier, 1826. Von Baer was the founder of Embryology, establishing the doctrine *omnia ex ovo*, 1827; but the first researches in Reproduction were made by Fabricius about 1600, and by Harvey in 1651. Wolff, in the 18th century, was the pioneer in observing the phenomena of Development. Sars first observed alternate generation, 1833. Duméril is considered the

father of Herpetology, and Owen of Odontology. Schleiden and Schwann published their celebrated researches in cell structure, 1841; but Bichat, who died 1802, was the founder of Histology. Protoplasm was discovered by Dujardin in 1835, and called *Sarcodæ*. The name *Protoplasma* was formally given to the slimy contents of vegetable cells by the German botanist, Hugo von Mohl, in 1846. The essential identity of the protoplasm of plants and of animals was first claimed by Max Schulze in 1861, who thus made one of the most important generalizations in science.

⁴ According to Mr. Darwin, the characters which naturalists consider as showing true affinity between two or more species are those which have been inherited from a common parent; and, in so far, all true classification is genealogical, *i.e.*, it is not a mere grouping of like with like, but it includes, like descent, the cause of similarity. In the existing state of science a perfect classification is impossible, for it involves a perfect knowledge of all animal structure and life history. As it is, it is only a provisional attempt to express the real order of nature, and it comes as near to it as our laws do in explaining phenomena. It simply states what we now know about comparative anatomy and physiology. As science grows, its language will become more precise and its classification more natural.

⁵ The term *type* is also used to signify that form which presents all the characters of the group most completely. Each genus has its typical species, each order its typical genus, etc. The word is also applied to the specimen on which a new species is founded. A *persistent type* is one which has continued with very little change through a great range of time. The family of oysters has existed through many geological ages.

⁶ The Coelenterata and Echinodermata together make up the *Radiata*, the old subkingdom of Cuvier. *Echinoderma* is probably more correct than *Echinodermata*, but we retain the old orthography.

⁷ Strictly speaking, no individual is independent. Such is the division of labor in a hive, that a single bee, removed from the community, will soon die, for its life is bound up with the whole. An individual repeats the type of its kingdom, branch, class, order, family, genus, and species, through its whole line of descent.

⁸ These definitions of the various groups are mainly taken from Agassiz. They are not practically very useful, as they are not used by working naturalists. The kind and degree of difference entitling a group to a particular rank varies greatly with the naturalist, and the part of the animal kingdom where the group is found. Some families of insects are separated by gaps less than those which divide genera of mammals.

⁹ The millepore coral, so abundant in the West Indian Sea, is the work of hydroids. The surface is nearly smooth, with minute punctures. Gegenbaur, Haeckel, and others hold that the acalephs have no body cavity at all, the internal system of canals being homologous with the intestinal cavity of other animals.

¹⁰ This digestive cavity is really homologous to the proboscis of the jellyfish, turned in. It is lined with ectoderm. The "body cavity" is not really such, but is homologous to the digestive sac of the hydra.

¹¹ Among the exceptions are *Tubipora*, which have eight tentacles and no septa, and the extinct *Cyathophylla*, whose septa are eight or more.

¹² The longer septa (called primary) are the older; the shorter, secondary ones are developed afterward. As a rule, sclerodermic corals are calcareous, and a section is starlike; the sclerobasic are horny and solid. The latter are higher in rank.

¹³ The most important genera are *Terebratula*, *Rhynchonella*, *Discina*, *Lingula*, *Orthis*, *Spirifera*, and *Productus*. The first four have representatives in existing seas. Most naturalists now admit their affinity to the worms, some still keep them in the branch Mollusca, while others include them in the separate branch Molluscoida.

¹⁴ Some starfishes (*Solaster*) have twelve rays. In all echinoderms, probably, sea water is freely admitted into the body cavity around the viscera.

¹⁵ The shell is not strictly external, like the crust of a lobster, but is covered by the external skin.

¹⁶ Six hundred pieces have been counted in the shell alone, and twelve hundred spines. The feet number about eighteen hundred. They can be protruded beyond the longest spines.

¹⁷ Certain crabs live on dry land, but they manage to keep their gills wet.

¹⁸ The student should remember that this threefold division is not equivalent to the like division of a vertebrate body.

¹⁹ Each ring (called *somite*) is divisible into two arcs, a dorsal and ventral.

²⁰ The eye stalks were formerly considered to be appendages, but are no longer so regarded.

²¹ These parts do not correspond to the parts so named in human anatomy. See also pp. 371, 372.

²² The four pairs of legs in arachnids answer to the third pair of maxillæ and the three pairs of maxillipedes in the lobster. The great claws of scorpions and the pedipalpi of spiders correspond to the first maxillæ of the lobster.

²³ Compare the single thread of the silkworm and other caterpillars.

²⁴ The common spider, *Epeira*, which constructs with almost geometrical precision its net of spirals and radiating threads, will finish one in forty minutes, and just as regularly if confined in a perfectly dark place.

²⁵ There are some exceptions: the *oyster* is unequivalved, and the *pecten* equilateral.

²⁶ The chief impressions left on the shell are those made by the muscles—the dark spots called "eyes" by oystermen; the pallial line made by

the margin of the mantle ; and the bend in the pallial line, called *pallial sinus*, which exists in those shells having retractile siphons, as the clam.

²⁷ The clam is the highest of lamellibranchs, and the oyster one of the lowest. The *Mya arenaria*, or "soft clam," has its shell always open a little; while *Venus mercenaria*, or "hard clam," keeps its shell closed when disturbed.

²⁸ The slug has no shell to speak of. It may be remembered, as a rule, that all univalve shells in and around the United States are gastropods, and that all bivalves in our rivers and lakes, and along our seacoasts (save a few brachiopods), are pelecypods (lamellibranchs).

²⁹ Hold the shell with the apex up and the mouth toward the observer. If the mouth is on his right, the shell is right-handed or *dextral*, if on his left, *sinistral*. In other words, a right handed shell is like a right-handed screw.

³⁰ Instead of a strong breathing tube with a valve, answering for a force-pump and propeller, as in the cuttlefish, it has only an open gutter made by a fold in the mantle, like the siphons of the gastropods. The back chambers are filled with gas.

The common poupe has two thousand suckers, each a wonderful little pump, under the control of the animal's will.

³¹ The facial angle becomes of less and less importance as we go away from man, and for two reasons. Where the brain does not fill the brain case the angle is obviously of little value, and if the jaws are largely developed the angle is reduced, although intelligence may not be altered.

³² Oblong human skulls, whose diameter from the frontal to the occipital greatly exceeds the transverse diameter, are called *dolichocephalic*; and such are usually *prognathous*, i.e., have projecting jaws, as the negro's. Round skulls, whose extreme length does not exceed the extreme breadth by a greater proportion than 100 to 80, are *brachycephalic*; and such are generally *orthognathous*, or straight-jawed.

³³ The classes are variously grouped into the *Hematocrya*, or cold-blooded, and the *Hematotherma*, or warm-blooded; into the *Branchiata* and *Abranchiata*; into the *Allantoidea* and *Anallantoidea*.

³⁴ Amphibians with a moist skin are also remarkable for their cutaneous respiration. They will live many days after the lungs are removed. Their vertebræ vary in form: in the lowest they are biconcave, like those of fishes; in salamanders they are opisthocœlous: in the frogs and toads they are usually proœlous.

³⁵ Salamanders are often taken for lizards, but differ in having gills in early life and a naked skin. The proteus and siren resemble a tadpole arrested in its development.

³⁶ The Surinam toad has no tongue.

³⁷ There are some notable exceptions. The slow worm is legless, and the chameleon has a soft skin, with minute scales.

³⁸ The posterior pair of limbs is sometimes represented by a pair of small bones; and the boas and pythons show traces of external hind limbs.

³⁹ The plastron is formed partly of dermal and partly of endoskeletal pieces.

⁴⁰ Knees always bend forward, and heels always bend backward.

⁴¹ We cannot claim that this airy skeleton is necessary for flight. The bones of the bat are free from air, yet it is able to keep longer on the wing than the sparrow. The common fowl has a hollow humerus; while some birds of long flight, as the snipe and curlew, have airless bones.

⁴² Hopping is characteristic of and confined to the perchers; but many of them, as the meadow lark, blackbird, and crow, walk.

⁴³ This order is artificial. But it is better to retain it until ornithologists agree upon some natural arrangement.

⁴⁴ The whales are hairy during foetal life only.

⁴⁵ The manatee has 6; Hoffmann's sloth 6; and two species of three-toed sloth have respectively 8 and 9.

⁴⁶ As in the whale, porpoise, seal, and mole. Teeth are wanting in the whalebone whales, ant-eaters, manis, and echidna.

⁴⁷ The monotremes resemble marsupials in having marsupial bones, but have no pouch. They differ from all other mammals in having no distinct nipples.

⁴⁸ The pouch is wanting in some opossums and the dasyurus.

⁴⁹ The extinct horse (*Hipparion*) had three toes, two small hoofs dangling behind. The foot of the horse is of wonderful structure. The bones are constructed and placed with a view to speed, lightness, and strength, and bound together by ligaments of marvelous tenacity. There are elastic pads and cartilages to prevent jarring; and all the parts are covered by a living membrane which is exquisitely sensitive, and endows the foot with the sense of touch, without which the animal could not be sure-footed. The hoof itself is made of parallel fibers, each a tube composed of thousands of minute cells, the tubular form giving strength. There are three parts, "wall," "sole," and "frog" — the triangular, elastic piece in the middle, which acts as a cushion to prevent concussion and also slipping.

⁵⁰ The fore feet of the tapir have four toes, but one does not touch the ground.

⁵¹ The camel and llama are exceptional, having two upper incisors and canines, are not strictly cloven-footed, having pads rather than hoofs, and are hornless.

⁵² For the best account of the elephant, see Tennant's "Ceylon" or Brehm's "Thierleben."

⁵³ The hyena alone of the carnivores has only four toes on all the limbs, and the dog has four hind toes.

⁵⁴ The old term *Quadrumania* is rejected, because it misleads, for apes,

as well as men, have two feet and two hands. There is as much anatomical difference between the feet and hands of an ape as between the feet and hands of man. Owen, however, with Cuvier, considers the apes truly "four-handed."

⁵⁵ The eye orbits of the lemurs are open behind. The flying lemur (*Galeopithecus*) is considered an insectivore.

⁵⁶ It fails to cover in the howling monkey and siamang gibbon; but in the squirrel monkey it more than covers, overlapping more than in man. As to the convolutions, there is every grade, from the almost smooth brain of the marmoset to that of the chimpanzee or orang, which falls but little below man's.

⁵⁷ The tailed apes of the Old World have longer legs than arms, and generally have "cheek pouches," which serve as pockets for the temporary stowage of food.

⁵⁸ In the human infant, the sole naturally turns inward; and the arms of the embryo are longer than the legs.

⁵⁹ The aye-aye, one of the lowest of the lemurs, is remarkable for the large proportion of the cranium to the face.

⁶⁰ This feature was shared by the extinct *Anoplotherium*, and now to some extent by one of the lemurs (*Tarsius*).

⁶¹ We have treated man zoologically only. His place in nature is a wider question than his position in Zoölogy; but it involves metaphysical and psychological considerations which do not belong here.

⁶² This twofold division is arbitrary. No essential distinction, founded on the nature of the elements concerned, or the laws of their combination, can be made; and so many so-called organic substances, as urea, ammonia, alcohol, tartaric and oxalic acids, alizarine, and glucose, have been prepared by inorganic methods, that the boundary line is daily becoming fainter, and may in time vanish altogether. We would here utter our protest against the introduction of any more terms like *inorganic*, *invertebrate*, *acephalous*, etc., which express no qualities.

⁶³ Even the works of nearly all animals, as nests and burrows, are bounded by curved lines.

⁶⁴ *London Quarterly Review*, January, 1869, p. 142. It is true of any great primary group of animals, as of a tree, that it is much more easy to define the summit than the base.

⁶⁵ "There are certain phenomena, even among the higher plants, connected with the habits of climbing plants and with the functions of fertilization, which it is very difficult to explain without admitting some low form of a general harmonizing and regulating function, comparable to such an obscure manifestation of reflex nervous action as we have in sponges and in other animals in which a distinct nervous system is absent." — Professor WYVILLE THOMSON'S *Introductory Lecture at Edinburgh*.

⁶⁶ "If nature had endowed us with microscopic powers of vision, and the

integuments of plants had been rendered perfectly transparent to our eyes, the vegetable world would present a very different aspect from the apparent immobility and repose in which it is now manifested to our senses." — HUMBOLDT'S *Cosmos*, i., 341.

⁶⁷ See Gray's "Structural Botany," 6th ed., Introduction; also Rolleston's "Forms of Animal Life," Introduction.

⁶⁸ "Life has been called the vital force, and it has been suggested that it may be found to belong to the same category as the convertible forces, heat and light. Life seems, however, to be more a property of matter in a certain state of combination than a force. It does no work, in the ordinary sense." — Professor WYVILLE THOMSON.

⁶⁹ The vegetable cell usually consists of a cell wall surrounding the primordial utricle or protoplasmic sac. In animal cells the former, though often present, is usually not easily seen. As a general fact, animal cells are smaller than vegetable cells.

⁷⁰ Cells are not the sources of life, as once thought, but are the products of protoplasm. "They are no more the producers of vital phenomena than the shells scattered in orderly lines along the sea beach are the instruments by which the gravitation force of the moon acts upon the ocean. Like these, the cells mark only where the vital tides have been and how they have acted." — Professor HUXLEY.

⁷¹ Many of the bones of the skull are preceded by membrane — hence called *membrane bones*.

⁷² In the heart, the muscular fibers are striated, yet involuntary; but the sarcolemma is wanting.

⁷³ We may, however, infer that the animal functions are not absolutely essential to the vegetative, from the facts that plants digest without muscles or nerves, and that nutrition takes place in the embryo long before the nerves have been developed.

⁷⁴ Scorpions and spiders properly feed upon the juices of their victims after lacerating them with their jaws, but fragments of insects have been found in their stomachs.

⁷⁵ The real tongue forms the floor of the mouth, and is found as a distinct part in a few insects, as the crickets.

⁷⁶ In the cyclostomata, it is circular or oval.

⁷⁷ The mouth of the whale is exceptional, the walls not being dilatable. The act of sucking is characteristic of all young mammals, hence the need of lips.

⁷⁸ The ant-eater has two callous ridges in the mouth, against which the insects are crushed by the action of the tongue.

⁷⁹ The baleen plates do not represent teeth; for in the embryo of the whale we find minute calcareous teeth in both jaws, which never cut the gum. The whalebone is a peculiar development of hair in the palate, and under the microscope it is seen to be made up of fibers which are hollow tubes.

⁸⁰ The "tusks" of the elephant are prolonged incisors; those of the walrus, wild boar, and narwhal are canines.

⁸¹ "I was one day talking with Professor Owen in the Hunterian Museum, when a gentleman approached, with a request to be informed respecting the nature of a curious fossil which had been dug up by one of his workmen. As he drew the fossil from a small bag, and was about to hand it for examination, Owen quietly remarked, 'That is the third molar of the under jaw of an extinct species of rhinoceros.'" — LEWES'S *Studies in Animal Life*.

⁸² This gap or interspace, so characteristic of the inferior mammals, is called *diastema*. It is wanting in the extinct anoplotherium, is hardly perceptible in one of the lemurs, and is not found in man.

⁸³ In the spermaceti whale, the teeth are fixed to the gum.

⁸⁴ The iguana among reptiles, and fishes with pavement teeth, approach the mammal in this respect.

⁸⁵ This movement is called *peristaltic* or *vermicular*, and characterizes all the successive movements of the alimentary canal.

⁸⁶ Fishes and amphibians have no saliva, but a short gullet. Birds are aided by a sudden upward jerk of the head.

⁸⁷ Fishes and reptiles have no pharynx proper, the nostrils and glottis opening into the mouth.

⁸⁸ This movement of the pharynx and esophagus is wholly involuntary. Liquids are swallowed in exactly the same way as solids.

⁸⁹ The few animals in which the digestive cavity is wanting are called *agastric*, and agree in having a very simple structure. Such are some Entozoa (as tapeworm) and unicellular Protozoa (as *Gregarina*). They absorb the juices, already prepared, by the physical process of endosmose. There are other minute organisms (bacteria) which seem to be able to extract the necessary elements, C H O N, from the medium in which they live.

⁹⁰ The cavity of a sponge is perhaps homologous with the digestive cavity, but is not functionally such. Each cell lining it does its own digestion, taking the food from the water circulating in the cavity.

⁹¹ "Nothing is more curious and entertaining than to watch the neatness and accuracy with which this process is performed. One may see the rejected bits of food passing rapidly along the lines upon which these pedicellariæ occur in greatest number, as if they were so many little roads for the conveying away of the refuse matters; nor do the forks cease from their labor till the surface of the animal is completely clean and free from any foreign substance." — AGASSIZ'S *Seaside Studies*.

⁹² In the larva of the bee, the anal orifice is wanting.

⁹³ The length of the canal in insects is not so indicative of the habits as in mammals. Thus, in the carnivorous beetle the canal is nearly as long as, and more complicated than, it is in the nectar-sipping butterflies.

⁹⁴ The object of this is unknown. It does not occur in the oyster.

⁹⁵ In the nautilus, this is preceded by a capacious crop.

⁹⁶ In the shark, this is impossible, owing to a great number of fringes in the gullet hanging down toward the stomach.

⁹⁷ At the beginning of the large intestine in the lizards (and in many vertebrates above them, especially the vegetarian orders), there is a blind sac, called *cæcum*.

⁹⁸ The crocodile is said to swallow stones sometimes, like birds, to aid the gastric mill.

⁹⁹ In the crop of the common fowl, vegetable food is detained sixteen hours, or twice as long as animal food. The dormouse, among mammals, has an approach to a crop.

¹⁰⁰ In invertebrates, the gizzard, when present, is situated between the crop and the true stomach; in birds, it comes after the stomach.

¹⁰¹ The tapeworm has no digestive apparatus, but absorbs the already digested food of its host. This is no exception to the rule. The chemical preparation of the food has preceded its absorption.

¹⁰² We find the most abundant saliva in those mammals that feed on herbs and grain, but its action on starch is extremely feeble.

¹⁰³ The acid in the gastric juice has an important function in killing or preventing the growth of bacteria which are taken in with the food. The gastric juice also dissolves the albuminous walls of fat cells, thus permitting the contained fats to escape. The drops of fat fuse together into larger masses, which are later broken up into droplets or emulsified by the pancreatic juice.

¹⁰⁴ It is probable that the digestive part of the alimentary canal in all animals manifests a similar mechanical movement. It is most remarkable in the gizzard of a fowl, which corresponds to the pyloric end of the human stomach. This muscular organ, supplying the want of a masticatory apparatus in the head, is powerful enough to pulverize not only grain, but even pieces of glass and metal. This is done by two hard muscles moving obliquely upon each other, aided by gravel purposely swallowed by the bird. The grinding may be heard by means of the stethoscope.

¹⁰⁵ Chyle is opaque in carnivores; more or less transparent in all other vertebrates, as in birds, since the food does not contain fatty matter.

¹⁰⁶ In fishes, the villi are few or wanting. In man, they number about 10,000 to the square inch.

¹⁰⁷ Except, perhaps, the tendons, ligaments, epidermis, etc.

¹⁰⁸ The blood is colorless also in the muscular part of fishes. That of birds is of the deepest red. The coloring matter of the red blood in worms is not in the corpuscles, but in the plasma.

¹⁰⁹ Coagulation may be artificially arrested for a brief time by common salt. Arterial blood coagulates more rapidly than venous. The disposition of the red corpuscles in chains, or *rouleaux*, does not occur within the blood vessels. The cause has not been discovered.

¹¹⁰ The corpuscles of invertebrates are usually colorless, even when the blood is tinged.

¹¹¹ Except during the foetal life. The corpuscles of the camel are non-nucleated, as in other mammals. If the transparent fluid from a boil be examined with a microscope, it will be seen to be almost entirely composed of colorless corpuscles.

¹¹² There are no valves in the veins of fishes, reptiles, and whales, and few in birds.

¹¹³ Capillaries are wanting in the epidermis, nails, hair, teeth, and cartilages. Hence, the epidermis, for example, when worn out by use, is not removed by the blood, like other tissues, but is shed.

¹¹⁴ A part of the blood, however, in going from the capillaries of the digestive organs to the heart, is turned aside and made to pass through the liver and kidneys for purification. This is called the *portal* circulation, and exists in all vertebrates, except that in birds and mammals it is confined to the liver.

¹¹⁵ Two in the higher mammals, three in the lower mammals, birds, and reptiles. They are called *venæ cavae*.

¹¹⁶ Tricuspid in mammals, triangular in birds.

¹¹⁷ The pulse of a hen is 140 ; of a cat, 110 to 120 ; of a dog, 90 to 100 ; and of an ox, 25 to 42.

¹¹⁸ The bivalve brachiopods breathe by delicate fringed arms about the mouth, and by the "mantle."

¹¹⁹ The air bladder, found in most fishes, is another rudiment of a lung, although it is used, not for respiration, but for altering the specific gravity of the fish. In the gar pike of our Northern lakes it very closely resembles a lung, having a cellular structure, a tracheal tube, and a glottis. It is here functional. The gills represent lungs only in function ; they are totally distinct parts of the organism.

¹²⁰ In the human lungs they number 600,000,000, each about $\frac{1}{100}$ of an inch in diameter, with an aggregate area of 132 square feet. The thickness of the membrane between the blood and the air is $\frac{1}{2400}$ of an inch. The lungs of carnivores are more highly developed than those of herbivores. In the manatee, they are not confined to the thorax, but extend down nearly to the tail.

¹²¹ Crocodiles are the only reptiles whose nostrils open in the throat behind the palate, instead of directly into the mouth cavity. This enables the crocodile to drown its victim without drowning itself ; for, by keeping its snout above water, it can breathe while its mouth is wide open.

¹²² A rudimentary diaphragm is seen in the crocodile and ostrich.

¹²³ The poison glands of venomous serpents and the silk vessels of caterpillars are considered to be modified salivary glands. Birds, snakes, and cartilaginous fishes have no urinary bladder.

¹²⁴ Since the weight of a full-grown animal remains nearly uniform, it

must lose as much as it receives ; that is, the excretions, including the solid residuum ejected from the intestinal canal, equal the food and drink.

¹²⁵ Other names for derm are, *cutis*, *corium*, *enderon*, and *true skin*; and for epidermis, *cuticle*, *ecderon*, and *scarfskin*. The derm is often so intimately blended with the muscles that its existence as a distinct layer is not easily made out.

¹²⁶ Papillæ are scarcely visible in the skin of reptiles and birds.

¹²⁷ The animal basis of this structure is *chitin*, a peculiar hornlike substance found in the hard parts of all the articulated animals.

¹²⁸ The shell is always an epidermal structure, even when apparently internal. The horny "pen" of the squid, the "bone" of the cuttlefish, and the calcareous spot on the back of the slug are only concealed under a fold of the mantle. So the shell of the common unio, or fresh-water clam, is covered with a brownish or greenish membrane, which is the outer layer of the epidermis. Where the mantle covers the lips of a shell, as in most of the large sea snails, or where its folds cover the whole exterior, as in the polished cowry, the epidermis is wanting, or covered up by an additional layer.

¹²⁹ The pearls of commerce, found in the mantle of some mollusks, are similar in structure to the shell ; but what is the innermost layer in the shell is placed on the outside in the pearl, and is much finer and more compact. The pearl is formed around some nucleus, as an organic particle, or grain of sand.

¹³⁰ When the centrum is concave on both sides, as in fishes, it is said to be *amphicæalous*; when concave in front and convex behind, as in crocodiles, it is called *procæalous*; when concave behind and convex in front, as in the neck-vertebræ of the ox, it is *opisthocæalous*. In the last two cases, the vertebræ unite by ball-and-socket joints.

¹³¹ Whether the skull represents any definite number of vertebræ was long under discussion. We cannot speak of "cranial vertebræ" in the same sense as "cervical vertebræ." The most that can be said is that in a general way the skull is homologous to part of the vertebral column.

¹³² A few have but one pair, the whale and siren wanting the hind pair ; while some have none at all, as the snakes and lowest vertebrates. In land animals, the posterior limbs are generally most developed ; in aquatic animals, the anterior. Dr. Wyman contends that the limbs are tegumentary organs, and attached to the vertebral column in the same sense that the teeth are attached to the jaws. Other theories are that they originate from gill arches (Gegenbaur) or that they are remains of a once continuous lateral fin (Thacher).

¹³³ The first trace of muscular tissue is found in the stem of vorticella — an infusorian. In hydra we find neuro-muscular cells, and the jellyfishes have muscular tissue.

¹³⁴ The muscles of some invertebrates, as spiders, are yellow.

¹⁸⁵ The muscles of the heart and gullet are striped. In the lower animals these distinctions of voluntary and involuntary, striated and smooth, solid and hollow, muscles can seldom be made.

¹⁸⁶ The skeleton of the carrion crow, for example, weighs, when dry, only twenty-three grains.

¹⁸⁷ The dragon fly can outstrip the swallow; nay, it can do in the air more than any bird—it can fly backward and sidelong, to right or left, as well as forward, and alter its course on the instant without turning. It makes twenty-eight beats per second with its wings, while the bee makes one hundred and ninety, and the house fly three hundred and thirty. The swiftest race horse can run at double the rate of the salmon. So that insect, bird, quadruped, and fish, would be the order according to velocity of movement.

¹⁸⁸ The theory that flies adhere by atmospheric pressure is now abandoned.

¹⁸⁹ More precisely, the term *brain* applies only to the cerebrum, while the total contents of the cranium are called *encephalon*.

¹⁴⁰ The exact functions of the cerebrum are not yet clearly understood. If we remove it from fishes, or even birds, their voluntary movements are little affected, while the *Amphioxus*, the lowest of fishes, has no brain at all, but its life is regulated by the spinal cord. Such mutilated animals, however, make no intelligent efforts. The substance of the cerebrum, as also the cerebellum, is insensible, and may be cut away without pain to the animal; and when both are thus removed, the animal still retains sensation, but not consciousness.

¹⁴¹ It is very difficult to define sensation, or sensibility. The power is possessed by animals which have neither nervous system nor consciousness. These low manifestations of sensibility are called irritability—the power by which an animal is capable of definitely responding to a stimulus from without. The response is not called out by the direct action of the stimulus, but is determined mainly by the internal structure and condition of the animal.

¹⁴² Parts destitute of blood vessels, as hair, teeth, nails, cartilage, etc., are not sensitive.

¹⁴³ “Tentacles” and “horns” are more or less retractile, while antennæ are not, but are hollow. Antennæ alone are jointed.

¹⁴⁴ In man, the soft palate and tonsils also have the power of tasting.

¹⁴⁵ No organ of hearing has been discovered with certainty in the radiates and spiders. The “ear” of many lower animals is probably an organ for perceiving the animal’s position rather than sound—an “equilibrium organ.”

¹⁴⁶ It is wanting in the aquatic mammals. Crocodiles have the first representative of an outside ear in the form of two folds of skin.

¹⁴⁷ This, like the definition of smell and hearing, is loose language.

There is no such thing as sound till the vibrations strike the tympanum, nor even then, for it is the work of the brain, not of the auditory nerve. Sound is the sensation produced by the wave movement of the air. If thus defined in terms of sensation, light is nothing; without eyes the world would be wrapped in darkness. Some Protozoa, as *Euglena*, have a pigment spot as an eye.

¹⁴⁸ In invertebrates and aquatic vertebrates, the crystalline lens is globular; or, in other words, it is round in short-sighted animals, and flattish in the long-sighted. The lens of the invertebrate is not exactly the same as the lens of the vertebrate eye, though it performs the same function; it is really a part of the cornea.

¹⁴⁹ The ant has 50 in each eye, the house fly 4000, the dragon fly 28,000.

¹⁵⁰ The pigment, therefore, while apparently in front of the retina, is really behind it, as in vertebrates. The layer beneath the cornea, serving as an "iris," is wanting in nocturnal insects, since they need every ray of light. The optic nerve alone is insensible to the strongest light.

¹⁵¹ It should be noticed that this corresponds with another peculiar fact already mentioned, that either hemisphere of the brain controls the muscles on the opposite side of the body. In invertebrates, the motor apparatus is governed on its own side.

¹⁵² Sharks have eyelids, while snakes have none. The third eyelid (called *nictitating membrane*) is rudimentary in many mammals. It may be seen at the inner angle of the eye.

¹⁵³ An infant would doubtless learn to walk if brought up by a wild beast, since it was made to walk, just as an Infusorium moves its cilia, not because it has any object, but because it *can* move them. Newborn puppies, deprived of brains, have suckled; and decapitated centipedes run rapidly. Such physical instincts exist without mind, and may be termed "blind impulses."

¹⁵⁴ We say "apparently," because it may be a fixed habit, first learned by experience, transmitted from generation to generation. A duckling may go to the water, and a hound may follow game in some sense, as Sir John Herschel devoted himself to astronomy, inheriting a taste from his father. Breeders take advantage of this power of inheritance.

¹⁵⁵ We may divide the apparently voluntary actions of animals into three classes. First, *organic*, in which consciousness plays no part, and which are due wholly to the animal machine. Second, *instinctive*, in which consciousness may be present, but which are not controlled by intelligence. Third, *associative*, in which the animals act under conscious combination of distinct, single ideas, or past impressions. To these we may add *rational* acts, in which the mental process takes place under the laws of thought.

¹⁵⁶ "Thus, while the human organism may be likened to a keyed instrument, from which any music it is capable of producing can be called forth at the will of the performer, we may compare a bee, or any other insect, to

a barrel organ, which plays with the greatest exactness a certain number of tunes that are set upon it, but can do nothing else." — CARPENTER'S *Mental Physiology*, p. 61. This constancy may be largely due to the uniformity of conditions under which insects live.

¹⁵⁷ We may say, as a rule, that the proportion of instinct and intelligence in an animal corresponds to the relative development of the spinal cord and cerebrum. As a rule, also, the addition of the power to reason comes in with the addition of a cerebrum, and is proportioned to its development. Between the lowest vertebrate and man, therefore, we observe successive types of intelligence. Intelligence, however, is not according to the size of the brain (else whales and elephants would be wisest), but rather to the amount of gray matter in it. A honeycomb and an oriole's nest are constructed with more care and art than the hut of the savage. It is true, this is no test of the capability of the animal in any other direction; but when they are fashioned to suit circumstances, there is proof of intelligence in one direction.

¹⁵⁸ An exception to the general rule that the smaller animals have more acute voices.

¹⁵⁹ It is wanting in a few, as the storks.

¹⁶⁰ The nightingale and crow have vocal organs similarly constructed, yet one sings and the other croaks.

¹⁶¹ Egg cells and sperm cells are detached portions of the parental organisms. Generally, these two kinds of cells are produced by separate sexes; but in some cases, as the snail, they originate in the same individual. Such an animal, in which the two sexes are combined, is called an *hermaphrodite*.

¹⁶² The eggs of mammals are of nearly uniform size; those of birds, insects, and most other animals are proportioned to the size and habits of the adult. Thus, the egg of the æpyornis, the great extinct bird of Madagascar, has the capacity of fifty thousand humming-birds' eggs.

¹⁶³ As a general rule, when both sexes are of gay and conspicuous colors, the nest is such as to conceal the sitting bird; while, whenever there is a striking contrast of colors, the male being gay and the female dull, the nest is open. Such as form no nest are many of the waders, swimmers, scratchers, and goatsuckers.

¹⁶⁴ This lies at first transversely to the long axis of the egg. As the chick develops, it turns upon its side.

¹⁶⁵ The blood appears before the true blood vessels, in intercellular spaces. It is at first colorless, or yellowish.

¹⁶⁶ Exactly as the blood in the capillaries of the lungs is aerated by the external air.

¹⁶⁷ Thus, the hollow wing bone was at first solid, then a marrow bone, and finally a thin-walled pneumatic bone. The solid bones of penguins are examples of arrested development.

¹⁶⁸ The thigh bone ossifies from five centers. The bone eventually unites to one piece.

¹⁶⁹ For this reason, mammals are called *viviparous*; but, strictly speaking, they are as oviparous as birds. The process of reproduction is the same, whether the egg is hatched within the parent or without. The eggs of birds contain whatever is wanted for the development of the embryo, except heat, which must come from without. Mammals, having no food yolk, obtain their nutrition from the blood of the parent, and after birth from milk.

¹⁷⁰ The larvæ of butterflies and moths are called *caterpillars*; those of beetles, *grubs*; those of flies, *maggots*; those of mosquitoes, *wigglers*. The terms *larva*, *pupa*, and *imago* are relative only; for, while the grub and caterpillar are quite different from the pupa, the bee state is reached by a very gradual change of form, so that it is difficult to say where the pupa ends and the imago begins. In fact, a large number of insects reach maturity through an indefinite number of slight changes. The humblebee moults at least ten times before arriving at the winged state.

¹⁷¹ Every tissue of the larva disappears before the development of the new tissues of the imago is commenced. The organs do not change from one into the other, but the new set is developed out of formless matter. The pupa of the moth is protected by a silken cocoon, the spinning of which was the last act of the larva; that of the butterfly is simply inclosed in the dried skin of the larva, which is called *chrysalis* because of the golden spots with which it is sometimes marked. The pupa of the honey-bee is called *nymph*; it is kept in a wax cell lined with silk, which the larva spins. The time required to pass from the egg to the imago varies greatly; the bee consumes less than twenty days, while the cicada requires seventeen years.

¹⁷² Compare the amount of food required in proportion to the bulk of the body, and also with the amount of work done, in youth, manhood, and old age.

¹⁷³ Excepting, perhaps, that the new tail of a lizard is cartilaginous.

¹⁷⁴ The patella, or kneecap, has no representative in the adult fore limb.

¹⁷⁵ "The structure of the highest plants is more complex than is that of the lowest animals; but, for all that, powers are possessed by jellyfishes of which oaks and cedars are devoid." — MIVART.

¹⁷⁶ It is, however, true that the number of eggs laid is proportioned to the risk in development.

¹⁷⁷ See Lewes's charming "Studies of Animal Life." Doubtless an examination of all the strata of the earth's crust would disclose forms immensely outnumbering all those at present known. And even had we every fossil, we should have but a fraction of the whole, for many deposits have been so altered by heat that all traces have been wiped out. Animal

life is much more diversified now than it was in the old geologic ages ; for several new types have come into existence, and few have dropped out.

¹⁷⁸ Among the types characteristic of America are the gar pike, snapping turtle, hummers, sloths, and muskrat. Many of our most common animals are importations from the Old World, and therefore are not reckoned with the American fauna; such as the horse, ox, dog, and sheep, rats and mice, honeybee, house fly, weevil, currant worm, meal worm, cheese maggot, cockroach, croton bug, carpet moth, and fur moth. Distribution is complicated by the voluntary migration of some animals, as well as by man's intervention. Besides birds, the bison and seal, some rats, certain fishes, as salmon and herring, and locusts and dragonflies among insects, are migratory.

¹⁷⁹ When the cable between France and Algiers was taken up from a depth of eighteen hundred fathoms, there came with it an oyster, cockle shells, annelid tubes, polyzoa, and sea fans. Ooze brought up from the Atlantic plateau (two thousand fathoms) consisted of ninety-seven per cent of foraminifers.

THE NATURALIST'S LIBRARY

THE following works of reference, accessible to the American student, are recommended:—

General Works and Text-books

PARKER and HASWELL, Text-book of Zoölogy.
 CAMBRIDGE Natural History.
 KINGSLEY, Elements of Comparative Zoölogy.
 DAVENPORT, Introduction to Zoölogy.
 JORDAN and KELLOGG, Animals.
 AGASSIZ, Methods of Study in Natural History.
 AGASSIZ and GOULD, Principles of Zoölogy.
 ROLLESTON, Forms of Animal Life.
 LEWES, Studies of Animal Life.
 HUXLEY and MARTIN, Elementary Practical Biology.
 OWEN, Comparative Anatomy of Invertebrates and Vertebrates.
 PARKER and PARKER, Practical Zoölogy.
 MORSE, First Book of Zoölogy.
 PACKARD, Zoölogy.
 GEGENBAUR, Comparative Anatomy.
 PARKER, Zoöatomy.
 PARKER, Elementary Biology.
 KINGSLEY, The Riverside Natural History.
 THOMSON, Outlines of Zoölogy.
 CLAUS and SEDGWICK, Text-book of Zoölogy.
 THOMSON, The Study of Animal Life.
 LANKESTER, Zoölogical Articles.
 MARSHALL and HURST, Junior Course in Practical Zoölogy.
 LANG, Comparative Anatomy.
 SCHMEIL, Introduction to Zoölogy.

Invertebrates

HUXLEY, Anatomy of Invertebrated Animals.
 MACALLISTER, Introduction to Animal Morphology.
 BROOKS, Handbook of Invertebrate Zoölogy.
 SIEBOLD, Anatomy of Invertebrates.
 SHIPLEY, Zoölogy of the Invertebrata.
 McMURRICH, Invertebrate Zoölogy.
 PACKARD, Text-book of Entomology.

Vertebrates

HUXLEY, Anatomy of Vertebrated Animals.
 HUXLEY and HAWKINS, Atlas of Comparative Osteology.
 FLOWER, Osteology of Mammalia.
 CHAUVEAU, Comparative Anatomy of Domesticated Animals.
 MIVART, Lessons in Elementary Anatomy.
 WIEDERSHEIM, Comparative Anatomy of Vertebrates.
 MIVART, The Cat.
 GRAY, Anatomy, Descriptive and Surgical.
 QUAIN, Human Anatomy.
 REIGHARD and JENNINGS, The Cat.

Embryology

BALFOUR, Comparative Embryology.
 FOSTER and BALFOUR, Elements of Embryology.
 PACKARD, Life Histories of Animals.
 MINOT, Human Embryology.
 MARSHALL, Vertebrate Embryology.
 HERTWIG, Text-book of Embryology: Man and Mammals.
 KORSCHULT and HEIDER, Invertebrate Embryology.

Physiology

HUXLEY, Lessons in Elementary Physiology.
 CARPENTER, Comparative Physiology.
 FOSTER, Text-book of Physiology.
 MARTIN, The Human Body.
 GRIFFITHS, Physiology of the Invertebrates.
 LANDOIS and STIRLING, Human Physiology.
 BINET, Psychic Life of Micro-organisms.
 MORGAN, Animal Life and Intelligence.

Geographical Distribution

WALLACE, Geographical Distribution of Animals.
 MURRAY, Geographical Distribution of Mammals.
 BEDDARD, Zoögeography.

Microscopy

- CARPENTER, The Microscope and its Revelations.
 GRIFFITHS and HENFREY, The Micrographic Dictionary.

Evolution

- SCHMIDT, Descent and Darwinism.
 HAECKEL, History of Creation.
 DARWIN, Origin of Species.
 HUXLEY, Lay Sermons, etc.
 MIVART, Lessons from Nature.
 ROMANES, Darwin and after Darwin: I. The Darwinian Theory.
 ROMANES, The Scientific Evidences of Organic Evolution.
 MARSHALL, Lectures on the Darwinian Theory.
 WEISMANN, Essays on Heredity.

Special Works

- CLARK, Mind in Nature.
 AGASSIZ, Seaside Studies in Natural History.
 TAYLOR, Half-hours at the Seaside.
 KENT, Manual of the Infusoria.
 GREENE, Manuals of Sponges and Cœlenterata.
 DANA, Corals and Coral Islands.
 DARWIN, Vegetable Mould and Earthworms.

- VERRILL and SMITH, Invertebrates of Vineyard Sound.
 GOULD and BINNEY, Invertebrata of Massachusetts.
 WOODWARD, Manual of Mollusca.
 HYATT, Insecta.
 PACKARD, Guide to the Study of Insects.
 COMSTOCK, Manual for the Study of Insects.
 HOLLAND, The Butterfly Book.
 HOWARD, The Insect Book.
 SMITH, Economic Entomology.
 DUNCAN, Transformation of Insects.
 JORDAN, Manual of the Vertebrates of the Northern United States.
 COUES, Key to North American Birds.
 CHAPMAN, Handbook of Birds of Eastern North America.
 BAIRD, BREWER, and RIDGWAY, Birds of North America.
 BAIRD, Mammals of North America.
 ALLEN, Mammalia of Massachusetts.
 FLOWER and LYDEKKER, Mammals, Living and Extinct.
 SCAMMON, Marine Mammals of North Pacific.
 HARTMANN, Anthropoid Apes.
 PESCHEL, The Races of Man.
 MARSH, Man and Nature.
 TYLOR, Primitive Culture.
 NICHOLSON, Palæontology.
 POULTON, The Colors of Animals.

Of serial publications, the student should have access to the *American Naturalist*, *Science*, *American Journal of Science*, *Popular Science Monthly*, *Smithsonian Contributions*, and *Miscellaneous Collections*, *Bulletins* and *Proceedings* of the various societies, *Annals and Magazine of Natural History*, and *Nature*.

The following works are recommended as having no English equivalents: —

- | | |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| VOGT ET YUNG, Traite d'anatomie comparée pratique. | BRONN, Classen und Ordnungen des Thierreichs (unfinished and expensive, but indispensable to the working zoologist). |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|

Also the periodicals: —

Zoologischer Anzeiger.

Biologisches Centralblatt.

APPENDIX

THE following directions for experiments are given for the purpose of enabling the teacher and pupil to make further direct observation of the structure and functions of animals, and are supplementary to those given under the head of "Practical Zoölogy."

The experiments and dissections are purposely chosen with a view to their simplicity, and to the ease with which they may be performed. Constant reference is made to figures which will both guide and illustrate the dissections. More extended studies may be carried out with the aid of the various works mentioned on pages 483, 484.

CHAPTER V

The difficulty of distinguishing by ocular observation alone the lower animals from the lower plants may be illustrated by making a microscopic examination of drops of sediment from the bottom of a stagnant ditch. The water will probably be teeming with unicellular organisms, both animal and vegetable, which cannot be differentiated by characters of form, size, color, motion, etc., alone.

CHAPTER VII

It is especially important that the student become as familiar as possible with protoplasm by a personal study of its structure and physiology. For this purpose the most favorable objects are the Protozoa, which are readily obtained and easily prepared for examination. Directions are given on page 23. Compare with these the protoplasm seen in the cells of the

water plants, as *Nitella*, *Chara* (end cells of leaves, and in the colorless rhizoids), and *Anacharis*; in the stamen hairs of *Tradescantia*; in *Spirogyra*; in the cells of the bulb scales of the onion, etc.

CHAPTER VIII

In studying protoplasm, many kinds of cell will probably be seen. Those mentioned are especially large, and in them the protoplasm is likely to be in quite active motion. To illustrate cell structure use not only the lowest organisms, but also isolated cells from higher animals and plants — for example, blood cells from the frog and from the human body. Frog's blood may be obtained by killing the animal in a box in which has been placed a small wad of cotton saturated with chloroform; as soon as the frog is dead cut into its skin to make the blood flow, then on a glass slide mix a drop of the blood with a drop of a .75 per cent solution of salt in water, put on a cover glass, and examine under a one-fourth to one-sixth inch objective (Figs. 260, 261). Human blood may be obtained by pricking the finger and mounting the drop in the same manner (Fig. 259). Study also the cells seen in a drop of saliva. Some of these, the salivary corpuscles, are small and usually spherical in shape; others, the epithelium cells, come mainly from the lining membrane of the mouth, are polygonal in outline, have a large nucleus, and are frequently found in groups consisting of several cells. Ciliated cells are easily obtained by placing in a drop of water on a slide a small portion of the gill of a live oyster or clam, and picking it to pieces with dissecting needles (ordinary cambric needles fixed by the eye end into wooden penholders). Examine under a one-fourth or one-fifth inch objective. Some of the pieces will probably be seen swimming about by means of their cilia (Fig. 199, *b*). With these animal cells compare such vegetable cells as pollen grains, spores of fungi, the cells composing the bodies of some of the fresh-water algæ, etc.

As the satisfactory preparation of the tissues requires skill obtained only by long training in manipulation and in the use of hardening fluids, stains, etc., in many cases it will be prefer-

able to buy prepared specimens. These may be obtained at slight expense from dealers in microscopic supplies. Such specimens, as well as sections of various organs, are very necessary, as it is only by a clear comprehension of the structure of the different tissues and of the organs which they compose that the student can understand the functions of the various parts.

CHAPTER XIII

The principal chemical changes taking place during digestion in the higher animals may be illustrated with very simple apparatus, and at the cost of but little time. It is not necessary that the student possess any knowledge of chemistry. The object of digestion, viz., the changing of substances which are incapable of absorption into substances which may be absorbed, can be made plain even to the youngest student. The chemicals needed may be obtained of any druggist.

The following experiments deal with the three principal digestive fluids, viz., saliva, gastric juice, and pancreatic juice; and with the main kinds of foods, *i.e.*, starchy, albuminous, and fatty substances.

SALIVARY DIGESTION

(1) *The microscopical appearance of undigested starch and its reaction with iodine*

Into a test tube about one fourth full of water put a pinch of corn starch and shake the tube. Notice that the starch does not dissolve. Examine a drop of the mixture under a microscope and note the starch grains floating about in the water. Add a drop or two of dilute iodine solution to the mixture in the tube and note that it turns a deep blue. Examine a drop of this mixture under the microscope and note that each starch grain has turned blue.

Prepare another test tube with water and starch, and boil the mixture in the flame of an alcohol lamp or of a Bunsen burner, keeping the tube agitated all the time in order to prevent the

starch from sticking to the inside of the tube. Note that the starch swells up and forms a paste, but does not actually dissolve. Cool the paste by holding the test tube in cold water. When sufficiently cool add a drop or two of iodine and note that the starch turns blue. This change of color serves as a test for starch whether uncooked or cooked. Hence we see that undigested starch is in the form of granules which do not dissolve in water, but which turn blue when treated with iodine.

(2) *The chemical test for digested starch, i.e., grape sugar*

Into a test tube about one fourth full of water put a pinch of grape sugar, shake the tube, and note that the grape sugar dissolves. Test the solution with iodine and note that the blue color does not appear.

Prepare another solution and to it add about one fifth its volume of a strong solution of sodium hydrate, then to this mixture add a drop or so of a one-per-cent solution of cupric sulphate. Shake the tube to mix the contents thoroughly. Note the light blue color. Boil the contents of the tube and the color changes, varying from light yellow to orange or brick red. Hence it is seen that digested starch (grape sugar) dissolves in water, does not turn blue with iodine, but turns yellow or reddish when boiled with a mixture of sodium hydrate and cupric sulphate.

(3) *The digestion of starch by saliva*

Collect about a third of a test tube full of saliva, the flow of which may be promoted by chewing a piece of rubber or a button. Dip a piece of red litmus paper into the saliva and note that the paper becomes faintly blue, indicating that the saliva is slightly alkaline in its chemical reaction. In another test tube make a mixture of about equal parts of saliva and water, and to this add a few drops of cool starch paste. Hold the tube containing this mixture in the hand for five or ten minutes in order to keep it at the temperature of the body. After a few minutes pour a portion of the mixture in another tube and test with iodine, which will probably give the blue

color indicating the presence of starch. Pour a second portion into another tube, add sodium hydrate and copper sulphate, and boil. If the yellow color appears it indicates that some of the starch has already been digested by the saliva, *i.e.*, has been changed to grape sugar, which remains dissolved in the fluid in the test tube. If the yellow color does not appear on the first trial, make another after an interval of a few minutes.

(4) *To show that digested starch is capable of absorption, while undigested starch is not*

Prepare two dialyzers. The parchment, or parchment paper, which in each dialyzer separates the contents of the inner from the contents of the outer jar, may be considered to represent roughly the membrane lining the alimentary canal, through which membrane substances are absorbed into the system. Into the inner jar of one dialyzer put a solution of grape sugar; into the inner jar of the other put some thin starch paste. After an hour or two test the water in the outer jar of the first dialyzer for the presence of grape sugar: that in the outer jar of the other dialyzer for starch. It will be found that grape sugar—*i.e.*, digested starch—dialyzes, while undigested starch does not. In other words, undigested starch cannot be absorbed. The experiment may be varied by putting both grape sugar and starch paste into the same dialyzer. Or, a mixture of starch paste and saliva may be put into the one, while starch paste alone is put into the other dialyzer.

GASTRIC DIGESTION

(1) *Some of the chemical reactions of undigested albuminous substances (proteids)*

Into a bowl or beaker break the white of an egg, cut it to pieces with a pair of scissors, add fifteen or twenty times its bulk of water, mix thoroughly by stirring, but do not beat it, then strain through muslin to remove the fine flakes of coagulated matter.

(a) Fill a test tube one fourth full of the mixture and boil. The albumen coagulates.

(b) Prepare another tube and add a few drops of nitric acid. The albumen coagulates. Boil. The coagulated mass turns yellow. Cool the tube and add ammonia. The color deepens to orange.

(c) Prepare another tube and add a few drops of Millon's reagent. The albumen is coagulated, and, on boiling, turns reddish. If only a little proteid is present no coagulation will occur, but the mixture will redden when boiled.

(d) Make the contents of another tube strongly acid with acetic acid, then add a few drops of potassium ferrocyanide, and a white precipitate will form.

(2) *Some of the chemical reactions of digested proteids
(peptones)*

Make a peptone solution by dissolving some of Merck's peptone in water. Repeat the experiments given for proteids. Results similar to those in (b) and (c) will be obtained, but the peptone does not coagulate on boiling, nor does it give the white precipitate with acetic acid and potassium ferrocyanide.

(3) *To show that peptones are diffusible through membranes,
while proteids are not*

Prepare the two dialyzers as for the experiments with starch and grape sugar. Into the inner jar of one dialyzer put some of the white-of-egg mixture, and into the other some peptone solution. After a few hours test the water in the outer jar of each dialyzer. It will be found that the peptone passes through the membrane, while the proteid does not.

(4) *To show that the gastric juice digests proteids, i.e.,
changes them to peptones*

Prepare some artificial gastric juice as follows: Make some .2 per cent hydrochloric acid by mixing 5.5 cubic centimeters of hydrochloric acid (sp. gr. 1.16) with enough distilled water

to make one liter. In 100 cc. of this acidulated water put 100 milligrammes of a 6000 pepsin, or 150 mg. of a 4000, or 300 of a 2000 pepsin. Any commercial pepsin may be used. Prepare the proteid by boiling an egg, and then cutting the white into small cubes or shreds. In place of the boiled egg some of Merck's prepared fibrin may be used.

With litmus paper test the reaction of the artificial gastric juice. It will turn blue litmus paper red, thus showing that its reaction is acid.

Fill a test tube about one fourth full of the artificial gastric juice, and add a few pieces of coagulated white of egg or of fibrin; then set the tube in a warm place, as in a water bath regulated to about 37° C., or near a stove. Examine the tube from time to time. The cubes of egg will be seen to be disintegrating and dissolving.

A quantity of digested white of egg may be prepared in a cup or bowl and emptied into the inner jar of a dialyzer. After a time the water in the outer jar will give the peptone tests, showing that the digested albumen is diffusible.

PANCREATIC DIGESTION

Procure some of the commercial pancreatic preparations and make an artificial pancreatic juice according to the directions furnished with each preparation. Test the reaction with litmus paper. It will be found to be alkaline. Try the effect of the artificial preparation on starchy and on albuminous substances in the manner given above for each. The pancreatic juice will be found to change starch to grape sugar and proteids to peptones. Try its effect also on oil by adding a few drops of olive oil to some pancreatic juice in a test tube. At first the oil will float on the surface of the liquid. Shake the tube vigorously to mix the two substances. The oil will be broken up into fine droplets, giving the contents of the tube a milky appearance. On standing for a time it will be seen that the oil does not separate from the digestive juice and collect at the surface as it would if shaken up with water, but the two fluids remain intimately mixed, forming an *emulsion*. Under a microscope

examine a drop of the emulsion. It will be seen to consist of innumerable fine drops of oil, which remain separate from one another. If oil be shaken up with saliva or with artificial gastric juice no emulsion will be formed, the oil soon separating.

CHAPTER XV

Directions for obtaining and studying blood corpuscles are given in the notes on Chapter VIII. Sufficient blood to show the phenomena of clotting may be obtained by chloroforming a rabbit or a fowl, cutting one of the veins in the neck, and catching the blood in small tumblers or beakers.

CHAPTER XVI

The beat of the heart is very conveniently studied in the frog. Put a live frog into a glass bowl with a piece of cotton batting or of cloth saturated with chloroform, and cover the bowl. In a few minutes the animal will have become motionless and insensible. Remove it from the bowl; with a sharp knife divide the skin and cartilage at the base of the skull, thus making an opening into the brain cavity; into the latter thrust a wire, and by twisting it about destroy the brain. The frog will probably struggle, but its motions are reflex, and it has no consciousness of pain. The heart may now be exposed by making an incision through the skin and muscles of the upper part of the abdomen and removing the cartilaginous part of the breastbone. The heart will be seen beating inside the pericardium. The latter may be removed and the heart freely exposed. After studying the movements of the organ it may be removed from the body by cutting the blood vessels close to their junction with the heart, and placed on a plate of glass or in a watch glass containing .75 per cent salt solution. Its movements will continue a long time after its removal from the body. The organ may afterward be opened and the relation of its ventricle, auricles, and the connecting veins and arteries studied (Fig. 273).

The heart of the pig, sheep, or calf may be used to show the structure of the mammalian heart. It is best to procure at the meat shop several "plucks," *i.e.*, heart, lungs, and trachea all attached together. Instructions should be given the butcher that the parts are to be left intact, otherwise they will be found to be punctured with knife cuts. Dissect out the blood vessels for some little distance from the heart in order to get their relations. Open some of the hearts lengthwise, others crosswise, to show the internal structure (Fig. 271). Pour water into the cavities to show the action of the valves. The flow of blood through the heart may be illustrated by connecting the aorta with the venæ cavæ by means of rubber or glass tubing to represent the systemic circulation, and the pulmonary artery with the pulmonary veins to represent the pulmonary circulation, then filling the heart with water or a colored fluid and compressing the organ with the hand (Fig. 273).

The circulation may be studied in the web of the frog's hind foot. Procure a thin board large enough to lay the frog upon; in one end make a hole about a half-inch in diameter, over which the web may be stretched; anæsthetize the frog with ether or chloroform; as soon as the animal becomes insensible lay it on the board, with its body covered with a moist cloth; over the larger toes of the foot to be examined slip nooses of thread, and fasten these in slits around the edge of the board in such positions as to spread the web between two of the toes over the hole in the board. Put a drop of water on the web, lay on the cover glass, place the board on the microscope, and examine with a one fifth or a one sixth objective. The anæsthetic must be renewed from time to time, otherwise the struggles of the animal will interfere with observation (Fig. 263).

CHAPTER XVII

The gross structure of the frog's lung may be studied in specimens which have been removed from the body, inflated with air blown through a small glass tube inserted through the glottis, and placed in alcohol a few hours to harden. When

cut open the lung will be seen to be a hollow sac with corrugated walls (Fig. 282).

"Plucks" obtained from a butcher will illustrate the structure of the mammalian larynx, trachea, bronchial tubes, etc. If fresh and not punctured with the knife they may be inflated. To work well they should be kept moistened (Fig. 283).

The presence of carbon dioxide in the air exhaled from the lungs may be shown by using limewater or baryta water, with either of which carbon dioxide forms an insoluble precipitate, which at first floats as a delicate white film on the surface of the liquid. Pour some of the fluid into a saucer or watch glass, then breathe heavily upon it a few times through the mouth, and the film will be formed.

CHAPTER XVIII

The structure of the kidneys is well illustrated by the kidney of the sheep. Several of these should be procured and opened in various directions to show the structure (Fig. 290).

CHAPTER XIX

With little trouble skeletons of frogs, birds, and mammals with bones connected by flexible attachments may be prepared. Carefully cut away all of the muscles and other soft parts, leaving only the ligaments connecting the bones. Then place the roughly prepared specimen for one or two weeks in Wickersheimer's fluid, which is prepared as follows: In three liters of boiling water dissolve 100 grams of alum, 60 grams of caustic potash, 25 grams of salt, 12 grams of saltpeter, and 10 grams of arsenic. Cool and filter the liquid. Then to each liter of the fluid add 400 cubic centimeters of glycerine and 100 cubic centimeters of alcohol. The ligaments of skeletons soaked in this fluid will remain flexible during many months of exposure to the air. Should the ligaments become stiffened, their flexibility may be restored by a few hours' immersion in the fluid.

CHAPTER XX

Muscle fibers for microscopic examination may be obtained from the leg of a frog, or even from the body of a recently killed animal at the meat shop. Lay a small piece of muscle in a drop of .75 per cent salt solution on a glass slide, and with a pair of dissecting needles carefully pick the muscle to pieces. Some of the smallest shreds, upon examination with a one-fourth or a one-sixth inch objective, will be seen to be single or grouped muscle fibers, which will show the striations and the sarcolemma (Fig. 208).

CHAPTER XXI

Nerve fibers are readily obtained from the sciatic nerve in the frog. This nerve may be found by removing the skin from the back of a frog's thigh and carefully separating the underlying muscles. Among them will be seen the sciatic nerve, covered in places with dark gray or black pigment spots. Remove a quarter to a half inch of the nerve, being careful to stretch it as little as possible; lay it on the glass slide in a few drops of .75 per cent salt solution; cautiously tear it to pieces in the direction of its length with dissecting needles; then put on a cover glass and examine under a high power. The nerve will be found to consist of a number of nerve fibers, some of which will show the primitive sheath (*neurilemma*), medullary sheath, and axis cylinder (Figs. 210, 211).

The relation between the stimulation of a nerve and the contraction of the muscle to which the nerve runs may be shown as follows: Expose the sciatic nerve as directed above; then with the quick stroke of a sharp scalpel sever the upper end of the nerve as near the body as possible. At the moment of doing this the muscles of the leg and foot will probably contract. Allow the nerve to rest for a few minutes; then pinch its upper end with a pair of forceps. Again the muscles will contract. The stimulation may be repeated at intervals if the nerve be allowed to rest for a few minutes between successive stimula-

tions. Try also the effect of touching the nerve with a hot wire and with a drop of dilute acid or alkali. During experimentation the nerve preparation must be kept moistened with the salt solution.

CHAPTER XXIII

The structure of the egg may be studied in the starfish or sea urchin, frog or fowl. Starfish eggs preserved in various stages of segmentation may be purchased from the Department of Laboratory Supply of the Marine Biological Laboratory at Wood's Hole, Mass. Frogs' eggs may be found in ponds and ditches in early spring. If transferred to the laboratory and kept supplied with fresh water they may be watched through their various stages of segmentation to the formation of the tadpole, its liberation from the egg, and its later development. Compare with Fig. 370. To watch the development of a chick, eggs may be incubated by a hen or in an artificial incubator, one egg being removed each day, and opened by breaking away a circular piece of the shell on the upper side. If kept submerged in a dish of .75 per cent salt solution, warmed to the temperature of the body, the embryo chick may be kept alive for several hours to show the beating of the heart, etc. (Figs. 365, 366).

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